INTERIM REPORT - UPPER OTTAWA
STREET LANDFILL SITE STUDY,
REFERENCE PAPER 22 :
PRELIMINARY GEOPHYSICAL STUDIES

IPAL

Reference 22

PRELIMINARY GEOPHYSICAL STUDIES AT THE UPPER OTTAWA STREET LANDFILL

Submitted to Anne Koven of the

UPPER OTTAWA STREET LANDFILL SITE STUDY COMMITTEE

by

John Greenhouse

Waterloo Geophysics Inc.

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INTRODUCTION

On the basis of a letter from Ms. Koven dated May 6th we have undertaken some preliminary investigations at the Upper Ottawa Street site in order to:

i) Determine what geophysical techniques could confirm - or constrain - the presence of steel barrels within the landfill;

ii) Determine if geophysical methods could locate concentrations of toxic wastes (other than those in barrels) within the landfill mound.

SUMMARY OF FINDINGS

i) With regard to the barrel problem, there is no geophysical panacea. Ground-imaging radar, which has the potential to produce images of metal objects beneath the surface, appear on the basis of our preliminary tests to have a penetration of at most 3 metres. To that depth, then, barrels might be detected.

Below that depth, barrel detection from the surface must be accomplished by magnetometers and electro-magnetic detectors. These devices detect magnetic and electrically conducting materials respectively. They cannot, of course, distinguish between barrels and cars, sheet metal accumulation, etc.. Their resolution falls off very quickly with increasing depth to the source. These techniques could, however, put certain limits on how many barrels could - or could not - be at a certain depth.

Specifically, we conservatively estimate that about 2,500 barrels would have to be piled at (an average depth of) 30 metres, 300 barrels at 10 metres, or 20 barrels at 4 metres to produce a detectable anomaly. These estimates are derived from the data in Tables 1 and 2.

ii) Inductive resistivity can detect large changes in the bulk conductivity of the landfill mound to depths of 10-30 metres. Our preliminary readings at several locations on the till suggest that this bulk conductivity is quite uniform. A complete survey could detect variations, due to increases and decreases in the dissolved solid content of the landfill groundwaters, and at a reasonable cost. Dissolved solids are one measure of contamination, but not necessarily of toxicity. Dioxin, for example, does not contribute to the electrical conductivity of groundwater.

iii) This report attempts to define - as quantitatively as possible - the type of information that could be obtained with further geophysical surveys. The Study Committee must decide if this information is of value in meeting their objectives.

APPROACH

With assistant Mark Monier-Williams, and help from some geophysics students at the University of Waterloo, I have spent two afternoons running magnetic and electromagnetic surveys of two small (and presumably typical) areas on the landfill mound (A and B in Figure 1). I have also asked Dr. Peter Annan of A-Cubed Inc., Toronto, to spend one day with his crew and equipment evaluating ground penetrating radar for the detection of barrels at depth. Dr. Annan will report his results in detail separately.

METHODS

a. Magnetics. Steel barrels can be detected by a magnetometer because they are magnetic. The questions to be answered by this preliminary survey were:

i) What is the magnetic moment of a barrel? To what depth could a barrel - or pile of n barrels - be detected in a magnetically quiet environment.

ii) What is the background magnetic "noise" over the landfill, noise being defined as magnetic fields of other magnetic fragments scattered throughout the landfill. Any barrels would have to be detected through this noise, which therefore sets the detection threshold.

To answer question (ii) we have run magnetometer profiles - with station spacing between 1 and 5 metres - in areas A and B, and a 90 x 90 metre grid with 5 metre spacing in area A. For question (i), we measured the magnetic fields of some steel barrels at the University of Waterloo.

b. Electromagnetics (EM). To determine the conductive environment of the landfill, metal detection and ground conductivity EM instruments were read along profiles in area A. A shallow penetration Geonics EM-15 was used for the metal detection, EM-31 and EM-16R (VLF) for the ground conductivity.

The EM-31 and EM-16R instruments penetrate about 2 and 10 metres respectively, and measure the average electrical conductivity of the fill to that depth. Their response to metal is fairly insensitive, though these devices will detect massive accumulations of metal. As such these instruments give a measure of the dissolved solid concentration in the moisture of the fill. This in turn is

generally accepted as a measure of water contamination, and the geophysical measurements can therefore be taken as an indication of the landfill "strength" to the depth of penetration.

c. Ground Penetrating Radar (GPR). Whereas the geophysical EM instruments described above operate at frequencies of 5 to 20 khz, GPR generates at hundreds of megahertz. The advantage of GPR is that its wavelength is similar to the dimensions of a barrel, making the concept of "reflections" and "imaging" meaningful. The disadvantage is that the high frequencies are severely attenuated by the very conductive landfill. What needed to be ascertained here was whether the potential resolution would be nullified by the high attenuation.

A-Cubed personnel ran profiles along the sections of sites A and B, and then traversed the landfill ring-road along approximately one quarter of its length.

RESULTS

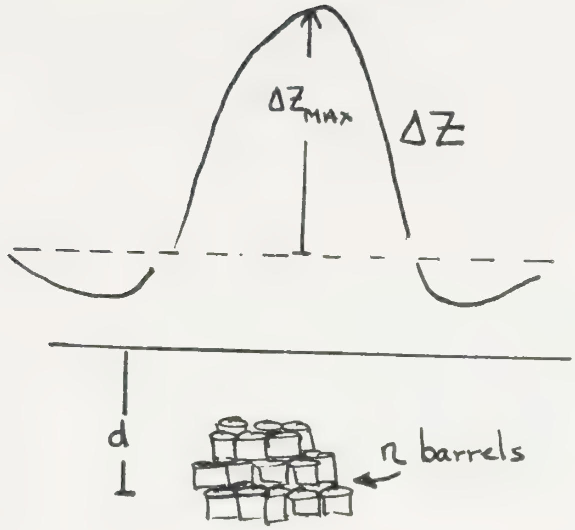
a. Magnetics

(i) Barrel anomalies. Figure 2 summarizes the vertical component magnetic anomalies over 3 barrel configurations. The barrels stood upright and measurements were made along profiles at barrel height (0.9 metres above ground), and at 1.6 metres and 2.2 metres above ground - using an aluminum stepladder.

At barrel height, anomalies of 30-40,000 gammas were recorded. At 1.3 metres above the barrel top, anomalies are on the order of 1,000-2,000 gammas. In other words, a single barrel buried at a depth to top of 1.3 metres in the Upper Ottawa Street landfill could be expected to produce a 1,000-2,000 gamma anomaly extending over a 1-2 metre interval.

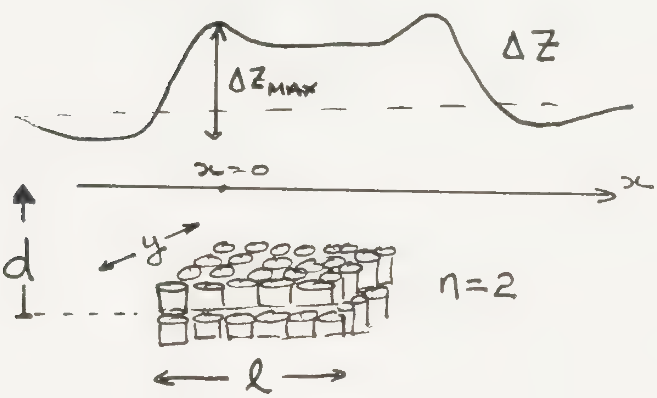
From this result we can attempt to construct the anomaly to be expected over a collection of barrels at various depths. Induced magnetization in a vertical geomagnetic field is assumed. Treating the single barrel as a dipole, the data in Figure 1 can be inverted to find a barrel dipole moment M_B of about 19 ampere·metres. Two formulae can be used to approximate the magnetic anomalies of groups of barrels.

A dipole approximation, for n barrels in a roughly spherical pile at depth-to-centre d, is:



$$\Delta Z_{MAX} = \frac{200\, M_B \cdot n}{d^3} \qquad (i)$$

A thin-sheet approximation for n stacked layers of upright barrels, depth to stack centre d and stack dimensions l x y square metres is:



$$\Delta Z \cong \frac{75\, M_B \cdot l \cdot y}{\cdot 2\, r^2 (r^2 + y^2)^{1/2}}$$

$$r = (x^2 + d^2)^{1/2} \qquad ii$$

where the factor ·2 represents the cross-sectional area of the barrels, and a factor of ·75 has been included to account for the circular barrel cross-section. Formulae (i) and (ii) are approximations: the actual anomalies could easily vary by a factor of 4.

Some typical anomalies are listed in Tables 1 and 2.

(ii) <u>Site Surveys</u>. Figures 3 and 4 show the readings along profiles at sites A and B respectively. Figure 5 is a contoured plot of the 90 x 90 metre area at site A.

In Figures 3 and 4 the readings are taken 5 metres apart, but some detail at 1 metre spacing is present in all three cases.

There can be no doubt that there are aliasing errors in the 5 metre profiles, as 1 metre variability can be typically 500 gammas. This interstation varability is very high by usual survey standards, due to many near-surface metal fragments. Nonetheless, in both the profile and areal surveys some longer wavelength trends (10-50 metres) show up, suggesting that there are regional variations in the magnetic metal content.

A highly smoothed, continuous recording magnetometer survey could average these near-surface effects but these preliminary results show that an accumulation of drums at depths below 3-4 metres must have a bare-minimum anomaly of 1,000 gammas to stand a chance of being isolated from the near surface noise. With reference to Tables 1 and 2 (choosing a few examples) we would need 10,000 barrels at 30 metres, about 2,500 barrels at 20 metres, 300 barrels at 10 metres, or 20 barrels at 4 metres to make detection possible. Even so, of course, the magnetometer can't tell car bodies from barrels; we are hoping that any other substantial source of magnetism has been removed by scrap dealers.

These data, then, have defined the minimum threshold of detection as 1,000 gammas.

Table 1. Some predicted magnetic anomalies over a roughly spherical pile of n barrels, depth to centre d.

d (m)	$\Delta Z(\gamma)$
1	$3800 \cdot n$
2	$475 \cdot n$
4	$59.4 \cdot n$
6	$17.6 \cdot n$
10	$3.8 \cdot n$
15	$1.12 \cdot n$
20	$.47 \cdot n$
30	$.14 \cdot n$

For example, n = 1000 barrels stacked in a cube 10 metres on a side at depth to centre 20 metres, should produce an anomaly of about 4,700 gammas.

Table 2. Some predicted magnetic anomalies ΔZ_{MAX} (gammas) over n stacked layers of barrels, each layer l metres square The depth to the centre of the stack is d metres ($n \leq d$).

l(n)	d(m) 1	2	5	10	20	30
.5	1100·n	150·n	10·n	1.2·n		
1	3200·n	500·n	40·n	5·n		
2	5800·n	1600·n	150·n	20·n		
5	"	3000·n	650·n	110·n		
10	"	"	1150·n	250·n	55·n	18·n
20	"	"	"	600·n	150·n	60·n
30	"	"	"	"	250·n	110·n
40	"	"	"	"	300·n	150·n

The total anomaly at the sheet edge tends to become independent of the stack dimensions for l >> d.

For example a stack of barrels 10 metres on a side, 2 layers deep, at a depth of 20 metres would have an anomaly of about 110 gammas

b. EM TECHNIQUES

(i) The conductivity environment of the fill. The EM-31 and EM-16R instruments respond primarily to the conductivity of the fill. Scattered EM-16R readings (not listed here) yielded consistent apparent resistivities between 6 and 9 ohm-metres, with phases between 52 and 70 degrees. Thus to a (skin) depth of about 10 metres the conductivity of the fill averages 8 ohm-metres, with lower conductivities at the surface.

The EM-31 profiles at site A, shown in Figures 6 and 7, give an average resistivity of about 12 ohm-metres. Since this device penetrates only about 2 metres, this average is consistent with the VLF phase results given above. The EM-31 does show a 30 metre segment of anomalously high conductivity in Figure 6, but its origins must lie in the very near surface.

In plain terms this is a very conductive environment, poorly suited for EM methods whose penetration is severely limited by these low resistivities.

The data from the EM-15 metal detector, shown in Figures 6 and 7, are not very informative. This device has a penetration of less than 2 metres.

c. Ground Penetrating Radar.

The results of the A-Cubed GPR survey have not been received in report form as of this writing. However, the preliminary conclusions of Dr. Annan were that penetration was at best 3 metres. If that proves to be the case, then GPR is of limited use for obtaining the objectives at hand.

CONCLUSIONS

a. Barrel Detection

The detectability of barrels has been constrained. As a very minimum, 20 barrels at depth 4 metres, 300 barrels at depth 10 metres, and 2,500 barrels at depth 30 metres will be necessary to produce an anomaly of 1,000 gammas that has a chance of being detected by the magnetometer survey through the high surface noise.

Were a detailed magnetometer survey undertaken, it could at best provide constraints. The best scenario would be to ask the geophysicist whether a certain area could contain a certain accumulation of barrels (perhaps reported from historical records). A survey could confirm whether the accumulation was plausible; only drilling could confirm it to everyones satisfaction.

Ground penetrating radar appears to have potential for locating barrels in the upper 3 metres only. The report of Dr. Annan may modify this conclusion, but no dramatic increases in depth capability are expected. An EM survey may help substantiate the magnetometer survey conclusions concerning barrels, but these techniques are to be considered secondary for this purpose.

A recommendation as to what further geophysical work should be done to detect barrels of toxic waste must now await the UOSLS committee's decision as to whether the information obtainable is worth the cost. A complete ground magnetometer and EM survey of the landfill would cost in the range of $10,000 - $20,000.00 if performed by a geophysical contractor. If the search could be narrowed to smaller areas of the site, costs would of course be less.

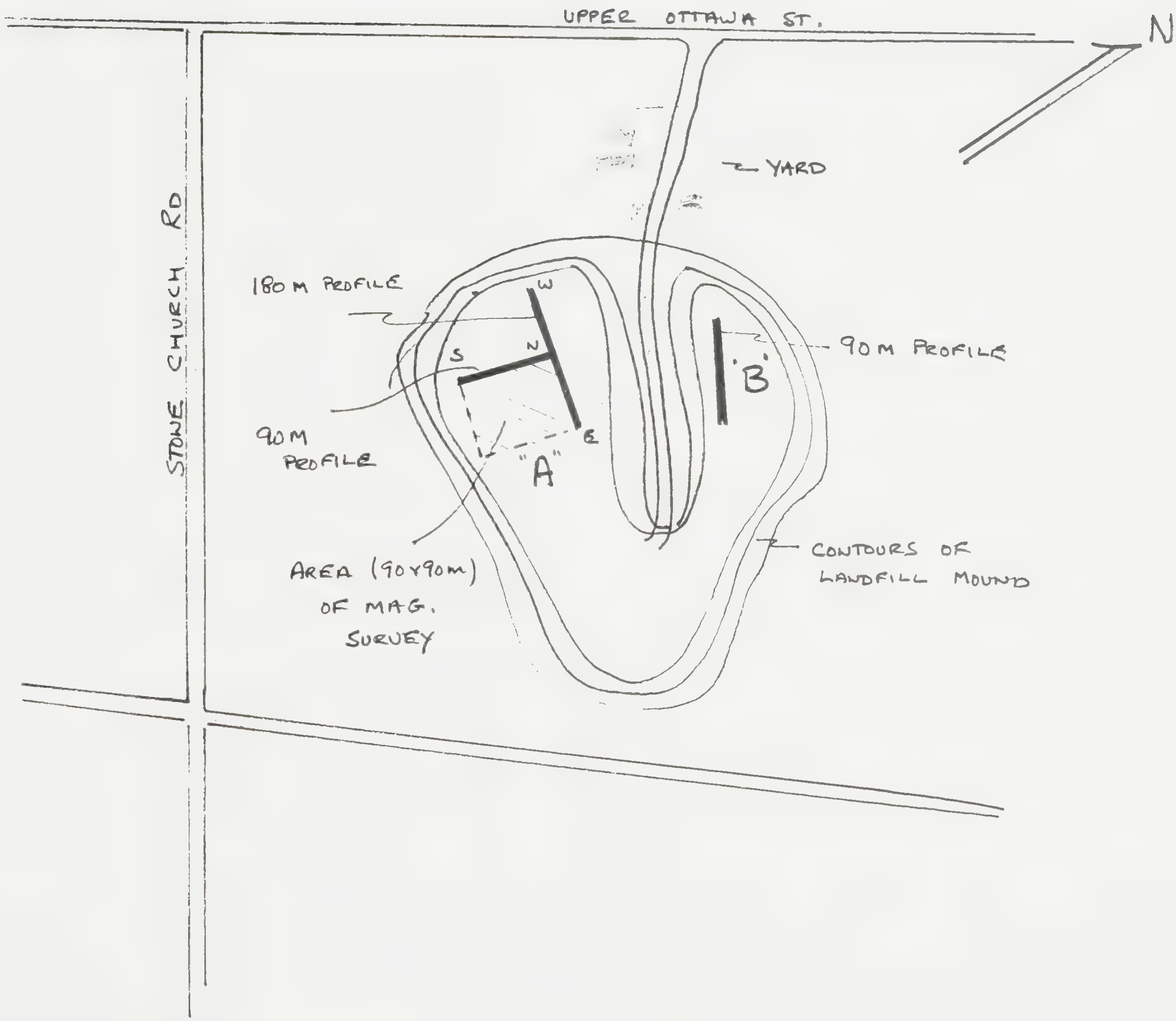
Ground penetrating radar can cover about 5,000 square metres per day with a 1 metre line spacing, at a cost of about $1,200.00 per day.

b. Contaminant Levels. The inductive resistivity devices, particularly the EM-16R and EM-34 (not used in this preliminary survey) have the capability of detecting the average soil moisture contamination levels to depths of about 20 metres. If concentrated "pools" of contaminant exist, then this might be determined at a reasonable cost. As has been noted, however, our (very limited) coverage to date suggests that the conductivity/contaminant levels are quite uniform over the site.

A suitable EM-34 and EM-16R survey of the entire site should require about one week's work and cost about $5,000.00.

FIGURE 1. SKETCH OF THE GEOPHYSICAL SURVEY LOCATIONS.

FIGURE 1.   SKETCH MAP OF THE GEOHYSICAL SURVEY LOCATIONS



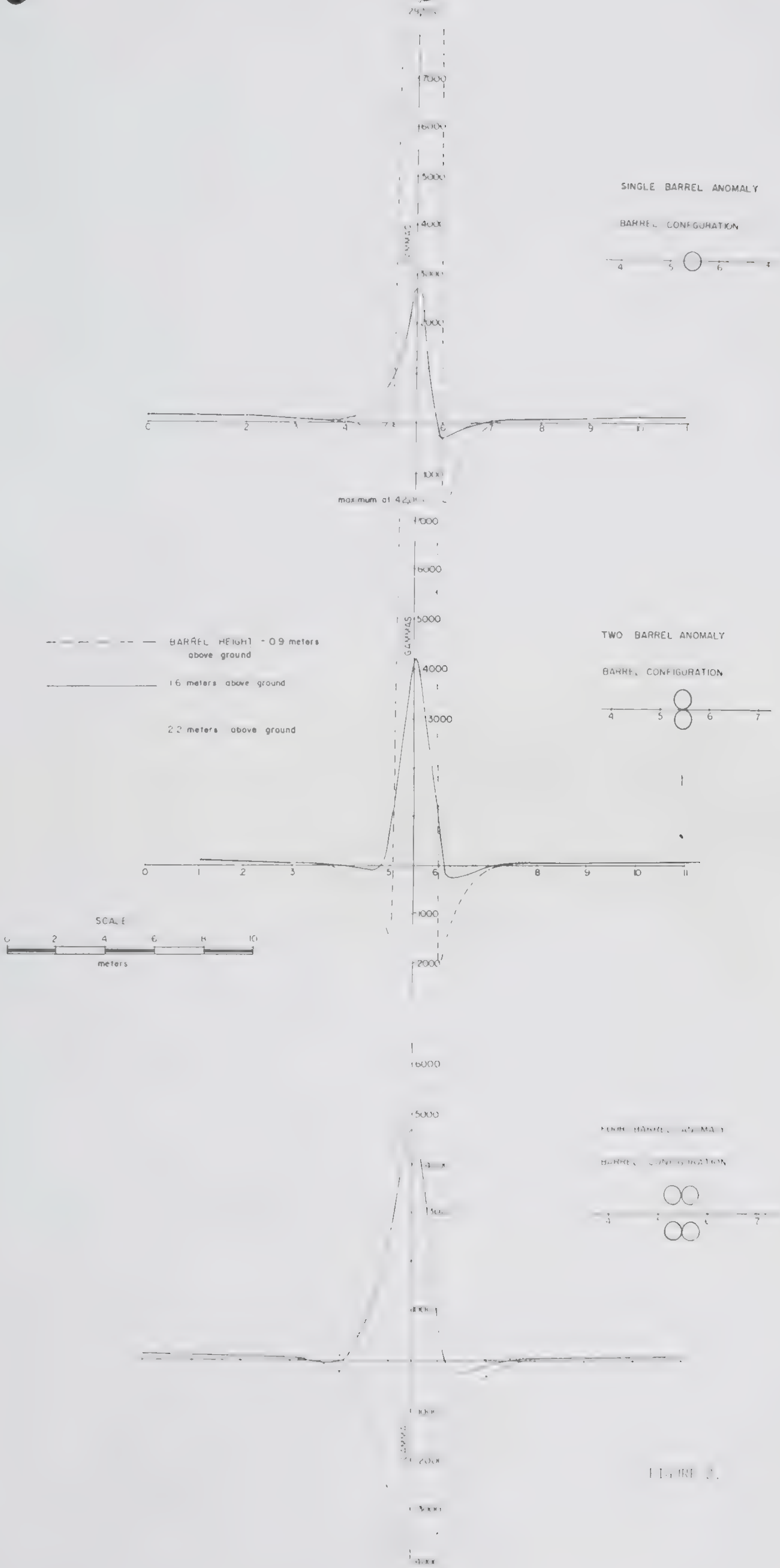

SINGLE BARREL ANOMALY
BARREL CONFIGURATION
TWO BARREL ANOMALY
BARREL CONFIGURATION
GAMMAS
maximum at 42,
BARREL HEIGHT - 0.9 meters above ground
1.6 meters above ground
2.2 meters above ground
SCALE
meters

FIGURE 3.

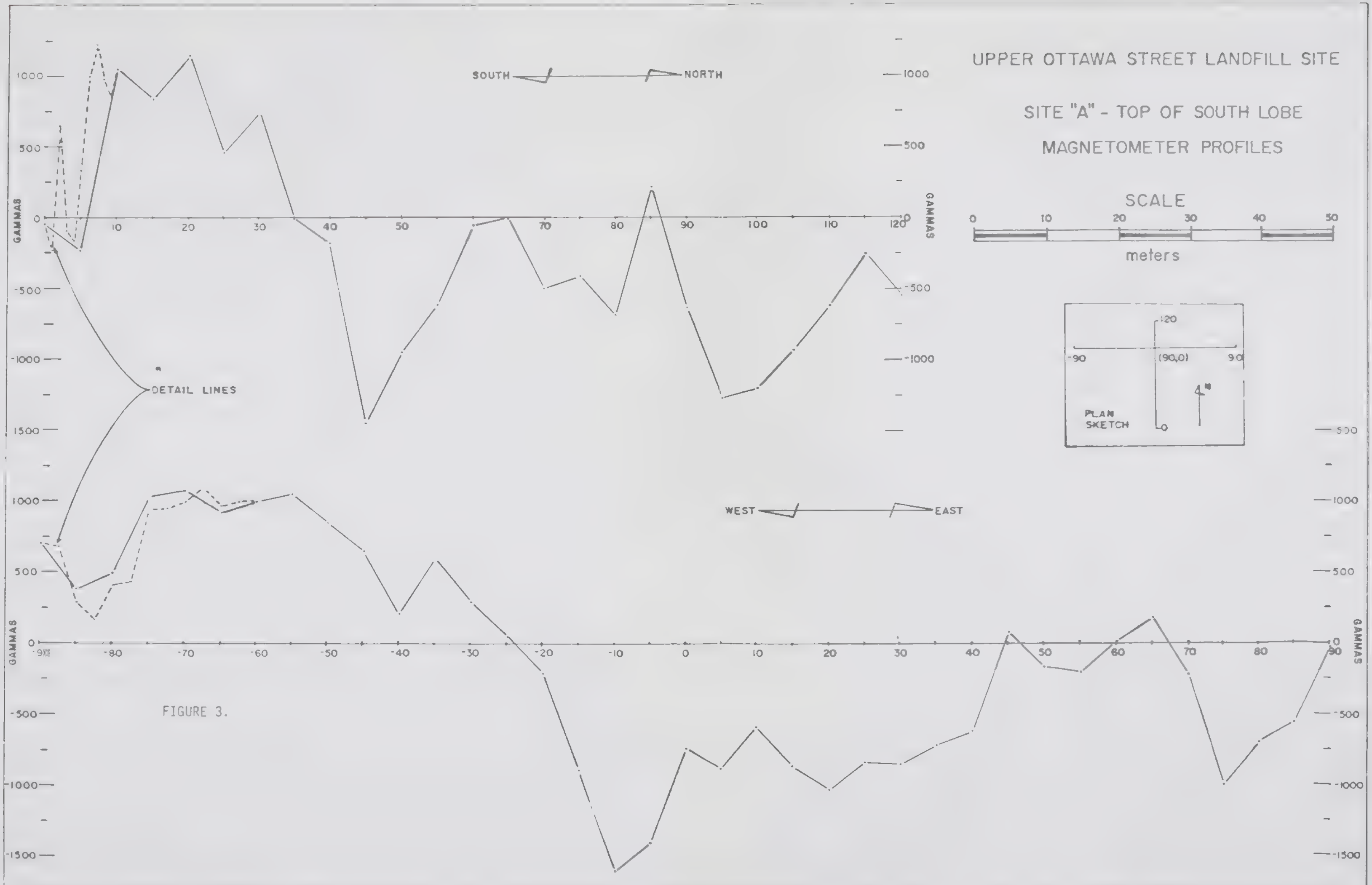

UPPER OTTAWA STREET LANDFILL SITE
SITE "A" - TOP OF SOUTH LOBE
MAGNETOMETER PROFILES
SCALE
0 10 20 30 40 50
meters
PLAN SKETCH
SOUTH
NORTH
WEST
EAST
DETAIL LINES
GAMMAS

FIGURE 3.

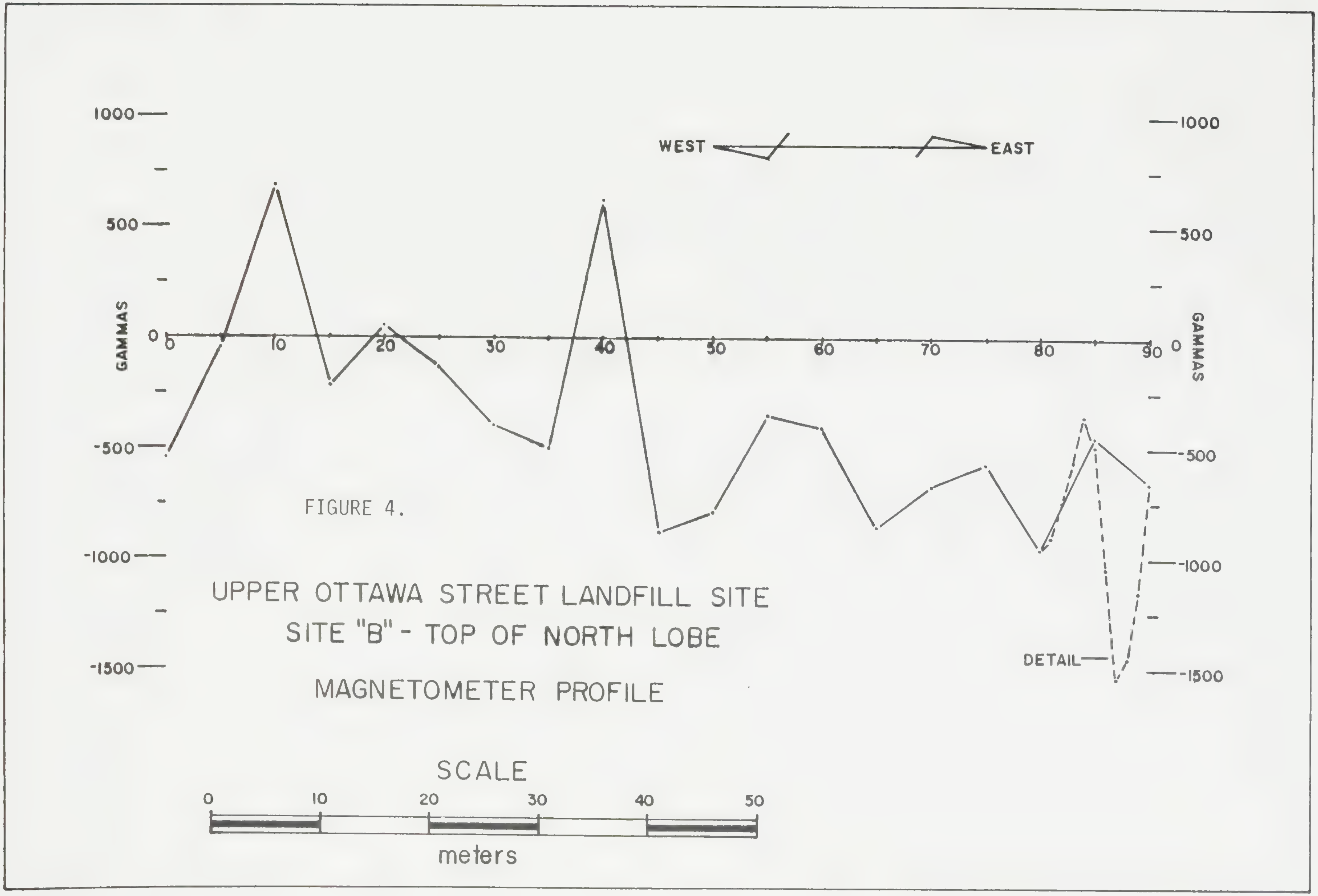
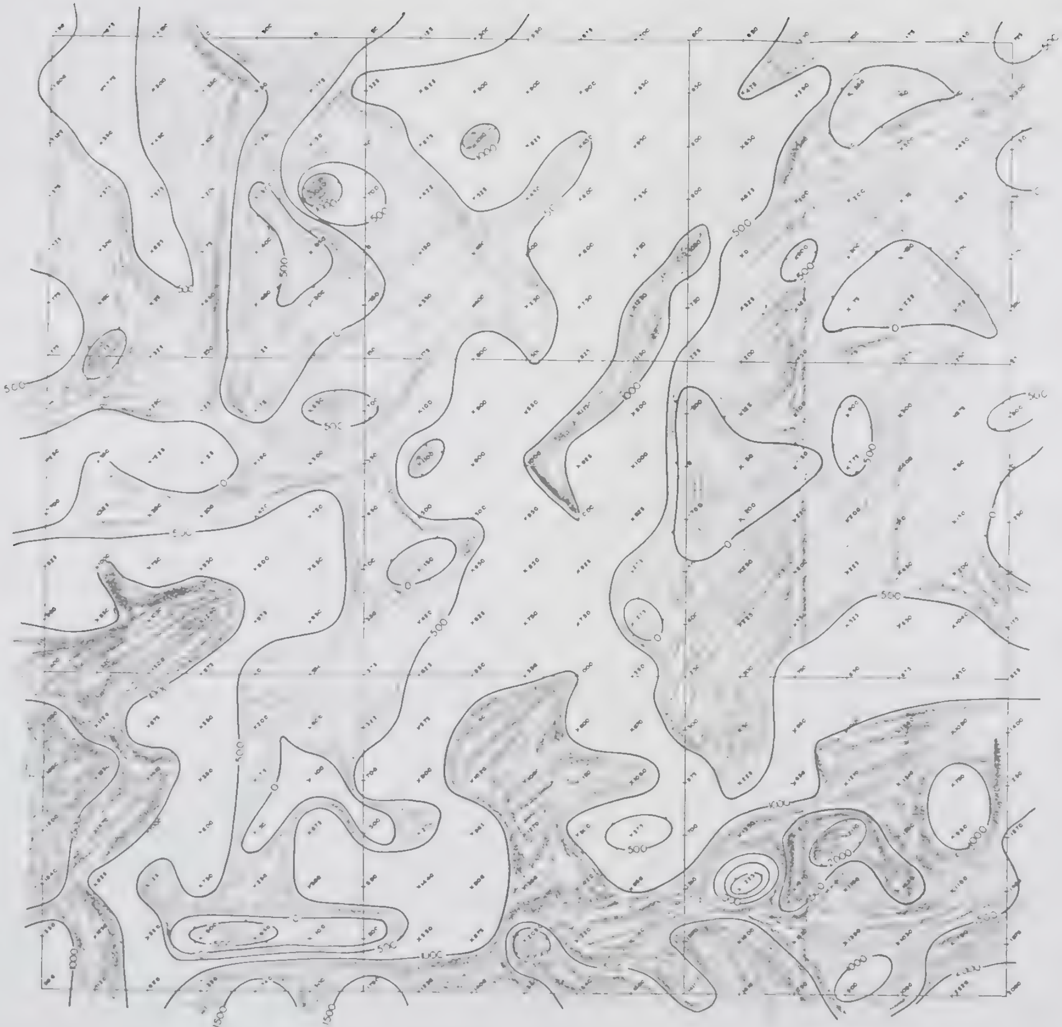


FIGURE 4.

UPPER OTTAWA STREET LANDFILL SITE
SITE "B" - TOP OF NORTH LOBE
MAGNETOMETER PROFILE



UPPER OTTAWA STREET
LANDFILL SITE

HAMILTON, ONTARIO

MAGNETOMETER GRID DATA

INSTRUMENT: Scintrex MF-2 Fluxgate Magnetometer

CONTOUR INTERVAL: 500 Gammas

SCALE

5 0 5 10 15 20 25

meters

- >2000 gammas
- 2000 to 1500 gammas
- 1500 to 1000 gammas
- 1000 to 500 gammas
- 500 to 0 gammas
- 0 to -500 gammas
- <-500 gammas

FIGURE 5.

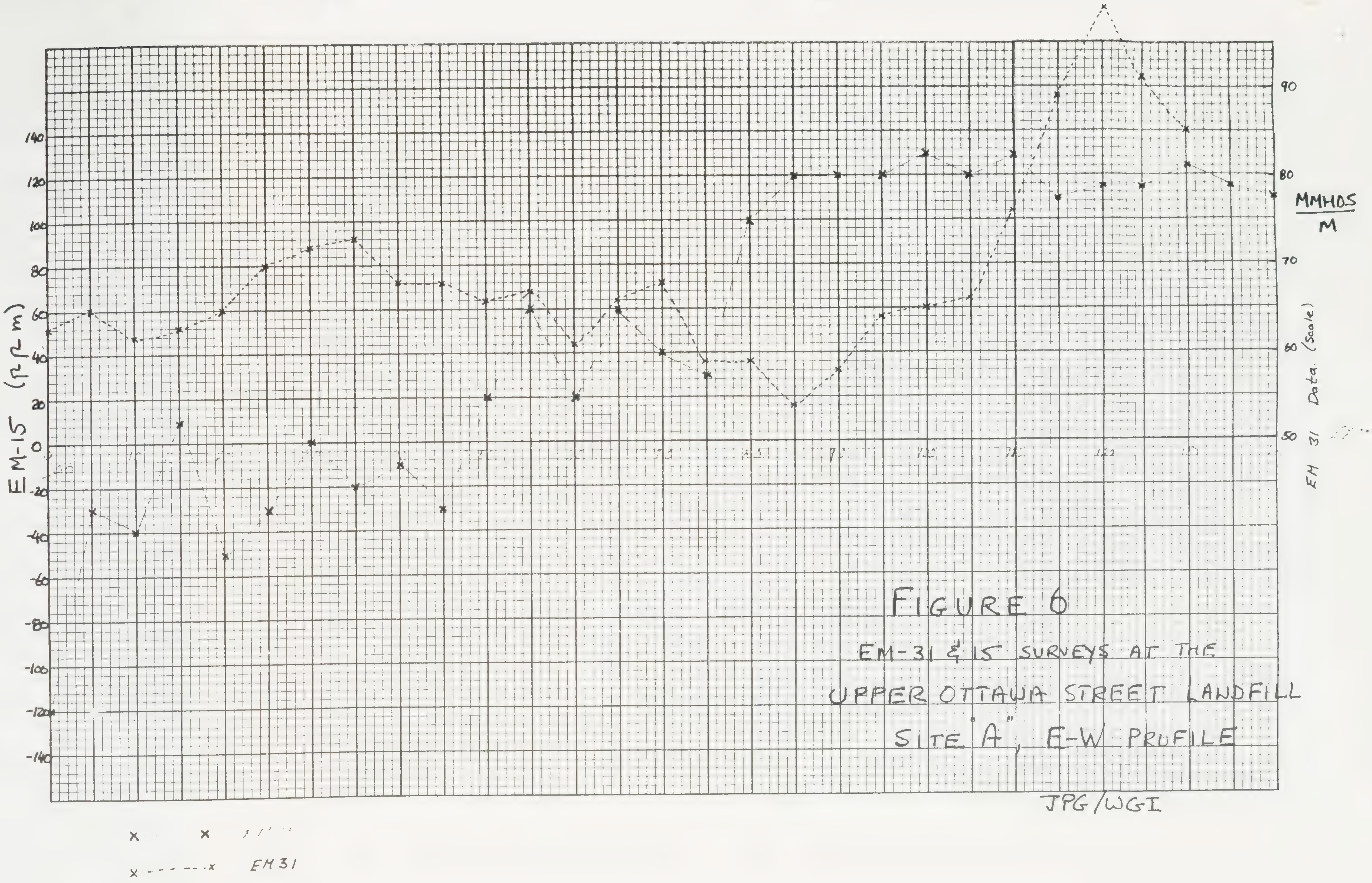


FIGURE 6

EM-31 & 15 SURVEYS AT THE UPPER OTTAWA STREET LANDFILL SITE "A", E-W PROFILE

JPG/WGI

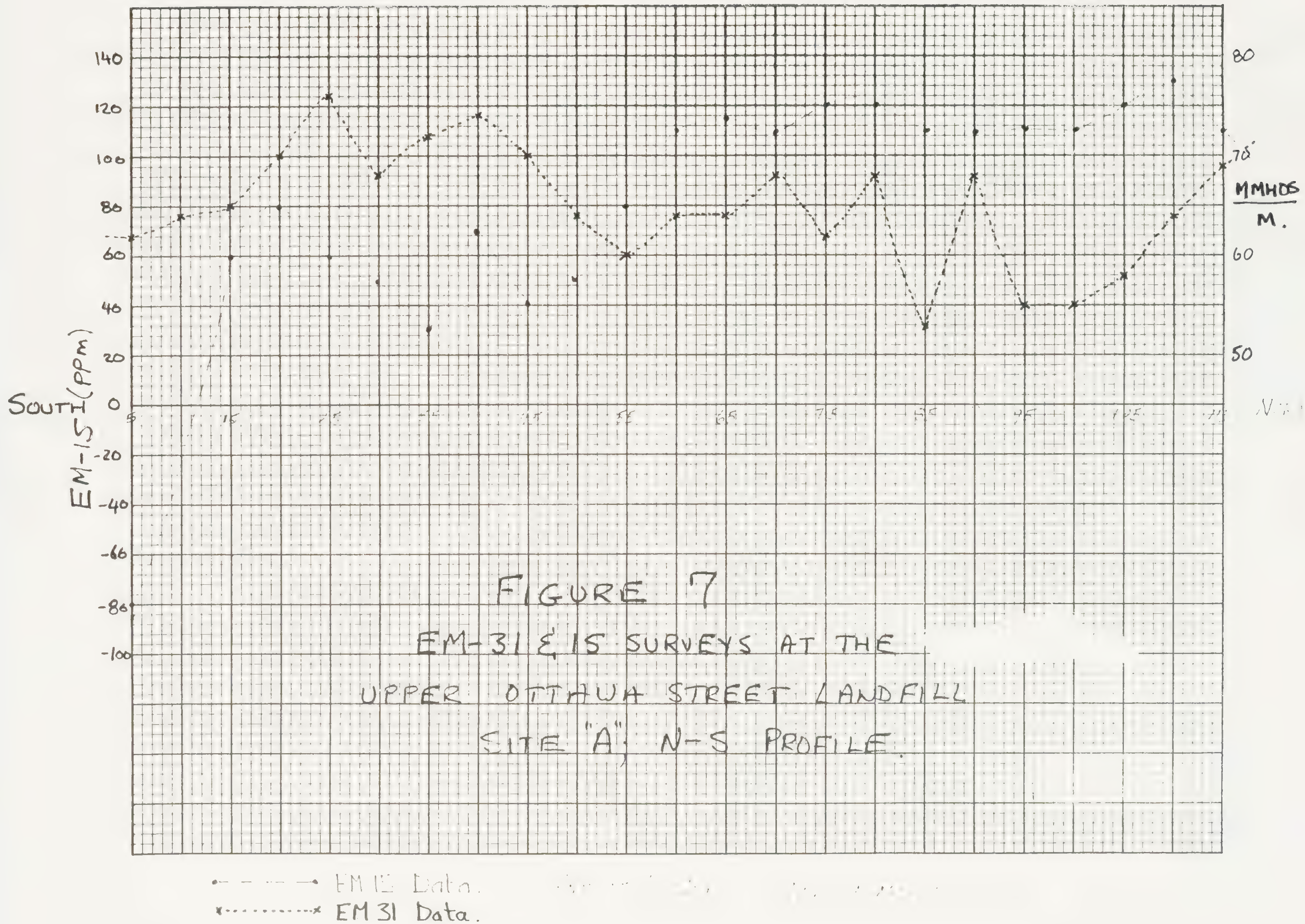


FIGURE 7

EM-31 & 15 SURVEYS AT THE

UPPER OTTAWA STREET LANDFILL

SITE "A", N-S PROFILE.

A-CUBED INC.
5566 TOMKEN ROAD
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Telex ~~06-961331~~
06-965537 A-CUBED MSG

September 3, 1982

Ms. Anne Coven
Research Director
Upper Ottawa Landfill Site Survey
42 James Street S.
Suite 33
Hamilton, Ontario
L8P 2Y4

Dear Ms. Coven:

Please find enclosed our report on the radar survey work carried out on the Upper Ottawa Landfill site. Also enclosed is an invoice for the work as agreed with Prof. Greenhouse from the University of Waterloo.

Yours truly,

A-CUBED INC.

A.P. ANNAN, Ph.D., P.Eng.
Chairman, Research Director

APA/gmh

Encl.

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REPORT ON UPPER OTTAWA LANDFILL SITE

TEST RADAR SURVEY

Distribution

1 - Upper Ottawa Landfill Site Study
1 - Dr. J.P. Greenhouse, Univ. of Waterloo
1 - A-Cubed Inc.

Project No: 5002

August 1982

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1. INTRODUCTION

A test radar survey was carried out on the Upper Ottawa Street landfill site in June of 1982. This survey work was carried out in conjunction with the University of Waterloo's investigation of the site on the feasibility of using geophysical methods to address the buried barrel problem in the area. The primary objective of carrying out the radar work was to assess whether or not the radar method would be of any use. Since the general electrical character of the site was totally unknown, the test survey was carried out in order to assess whether or not radar would penetrate into the landfill site. If any substantial penetration could be obtained with the radar then there was a good chance that high resolution radar might detect the buried barrels which were sought. If the radar failed to penetrate the landfill site material then radar could be ruled out as a viable means for investigation on the Upper Ottawa landfill site. The survey operation was therefore treated as a 'go' or 'no-go' evaluation of the site.

2. DESCRIPTION OF FIELD OPERATIONS

The radar method maps subsurface features by transmitting pulses of radio energy into the ground and detecting the reflections returned from buried features. A radar survey consists of transporting the radar sounding equipment over survey lines to map the location of reflectors. Some references to the radar method and examples of its application accompany this report in appendix B.

A 3 man survey crew from A-Cubed Inc. visited the Upper Ottawa landfill site on June 18, 1982. A series of radar profiles were run at four different locations to assess the viability of the radar on the site. A brief description of each survey location follows. Figure 1 presents a sketch map of the site indicating the areas surveyed.

The first line profile was a 150 metre long line running east/west along the top of the landfill site. This line was surveyed several times with the radar at different range and gain settings.

A second line, running north/south, was also profiled. This line ran perpendicular to the east/west line and was approximately 120 metres in length. In addition to surveying the 120 metres of line, the additional extension of the line down the side of the landfill site to a borehole well casing was also surveyed. This line was also surveyed several times at different range and gain settings. After the first traverse along this line, a heavy rain storm blanketed the area and all subsequent operations were carried out with a great deal of surface water visible.

A third line survey consisted of following the track, which circumscribes the whole landfill site, from the borehole at the end of the second survey line around to the west and then to the north, back to the east, until the road met the access road to the top of the landfill site. This line was traversed once and was surveyed after the rainfall.

The fourth area surveyed was the settling pond zone at the northwest extremity of the landfill site. A profile was run down a car or truck tyre track which ran roughly northwest-southeast along over the pond area. This line was surveyed from the southeast, starting at the access road, to the northwest where a well casing was located. The profile was then turned to the south and crossed over to a short section of line which had been surveyed with the magnetometer previously by the University of Waterloo Earth Sciences personnel.

In general, the amount of subsurface penetration which was obtained from preliminary analysis of the data was not very great. The heavy rainfall in the middle of the survey did not seem to have much of an effect on the penetration of the radar, which was minimal to start with. A major problem faced in carrying out this survey was the amount of radio or television signal interference which was received in conjunction with the system's own signal. This T.V. or radio signal appeared as random noise on the radar record, making deep reflections virtually impossible to detect, if any such reflections were present.

DESCRIPTION OF FIELD OPERATION (cont'd.)

The majority of the survey was carried out utilizing a 250 ns (nanosecond) range window. Since geological materials can have electromagnetic wave velocities of 0.05 to 0.12 m/ns, a 250 ns range corresponds to a maximum target depth of between 6.5 and 15 m. While some tests at 100 ns and 500 ns were made, the 250 ns appears most practical for the site.

3. DISCUSSION OF FIELD RESULTS

The field data is presented in Appendix A. Since very little subsurface information is available in the data, there is no need to carry out any detailed interpretation. Each of the records has been annotated with a time scale and an approximate depth scale, assuming a velocity of 0.08 m/ns. The horizontal position along each of the lines is also indicated.

By and large, the penetration of the radar was quite minimal, with maximum penetration appearing to be on the order of 1 to 3 metres. Even after the data had been replayed back in the lab several times, with varying amounts of filtering and various types of digital processing applied to try and remove some of the interference from the radio or T.V. stations, very little evidence of deep reflectors could be seen in the data.

While no deep features were observed in the data, several shallow features were noted along the various profiles. In general, the shallow information appeared to be a reflection from the top of the landfill material. This appeared to be a very erratic and irregular boundary, running about 0.5 to 1.5 metres below the surface. This was most evident on the east/west line on top of the landfill site. In addition, a number of small, strong, scattering features were noted along the lines in the very shallow surface material. These zones probably correspond to major pieces of metal in the top of the landfill material, or else localized pockets of increased thickness of the fill material covering the landfill.

Each of the sections in Appendix A has been annotated by marking horizontally continuous stratographic horizons with an orange marker and discrete localized events with a green marker. In many instances, the horizontal continuation of stratography is very sketchy and is not to be taken with too much confidence. The individual discrete events have been marked in green. These features may correlate with magnetometer features. There may also be some correlation of these features with the EM 31 conductivity data.

There is very little further to be said regarding the interpretation of the data, since there is very little subsurface information to interpet. It would, however, be useful to correlate the discrete radar features with the magnetometer and EM conductivity data in order to assess whether or not these features are real conductive or magnetic targets. Since these features are very shallow, they can probably be tested with a shovel or prybar without too much difficulty.

4. SUMMARY & CONCLUSIONS

The results of the survey, by and large, can be summarized very simply as being negative. The radar could not see to any substantial depth in the landfill material. The clay, silty material on the surface appeared to absorb a good deal of the energy transmitted by the radar. In addition, the landfill material appears to have a relatively high conductivity, indicating leachate is already present at relatively shallow depths in the landfill site. This information correlates with the few EM31 and EM16R conductivity measurements which were made by the University of Waterloo while they were on site, at the same time as the radar survey.

It is not felt that the site warrants any further use of the radar method at this time. The only chance that radar might be useful is if it provides some sort of correlation with the other geophysical techniques already tried. Should any future work be attempted, using the radar method on the landfill site, it is highly recommended that considerable effort be expended to try and minimize the amount of radio interference which would impact on the quality of the data. This would probably require surveying during the hours of midnight to 6 am. when most of the radio and T.V. stations close down or reduce power for the night.

A-CUBED INC.

REGISTERED PROFESSIONAL ENGINEER
A. P. ANNAN
PROVINCE OF ONTARIO

A.P. Annan, Ph.D., P.Eng.
Chairman, Research Director

UPPER OTTAWA STREET LANDFILL SITE

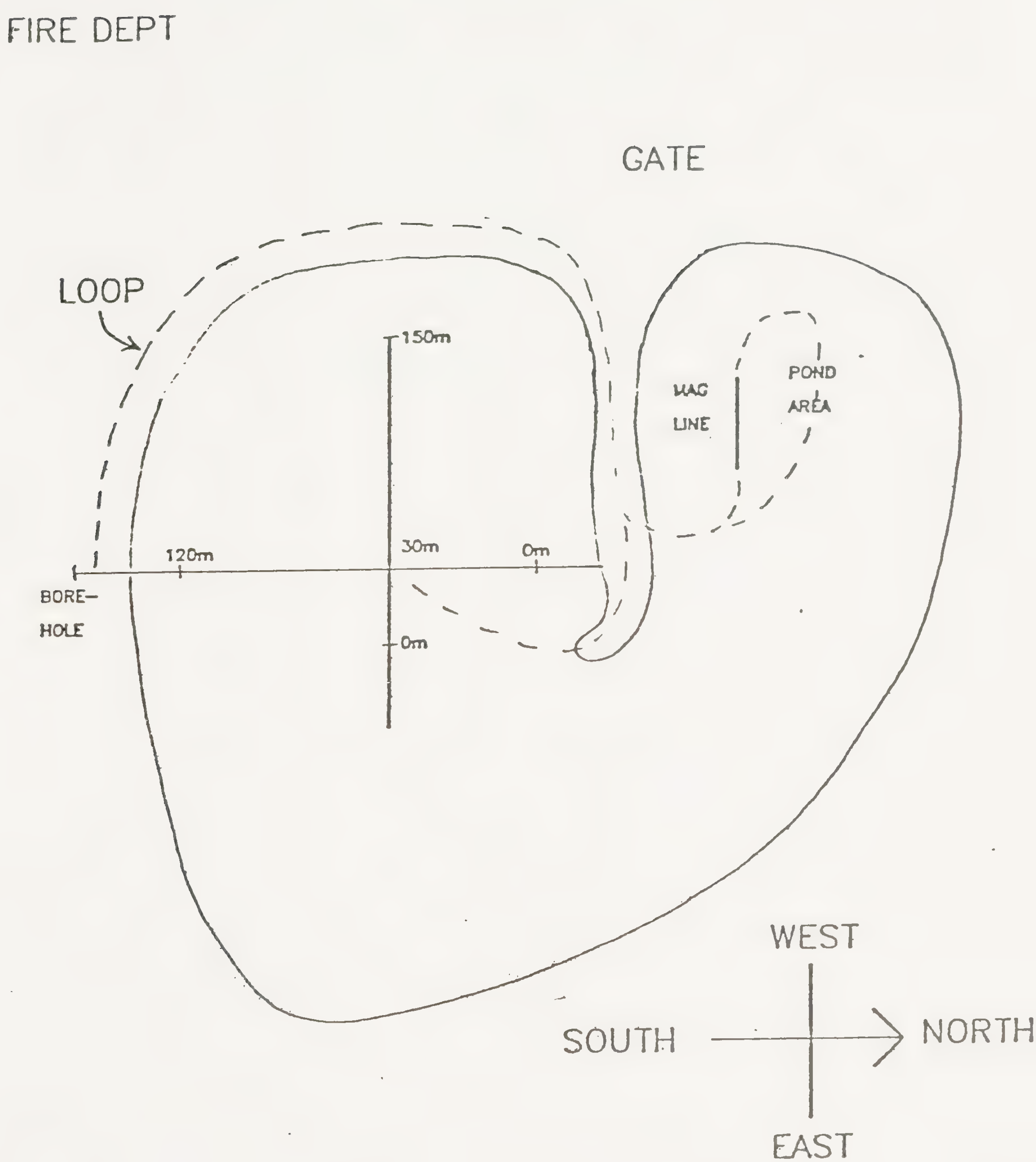

Figure 1

APPENDIX B

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AN APPLICATION OF IMPULSE RADAR TO DETAILED BURIED BEDROCK TOPOGRAPHY

Preprint for KEGS - CGU

Meeting May 11, 1982

May, 1982

A.P. Annan

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IMPULSE RADAR MAPPING OF BEDROCK DEPTH

1. Introduction

A-Cubed is pleased to present the following paper describing the application of impulse radar to mapping bedrock depth in an area of coarse, drained, overburden. Impulse radar is a technique for mapping bedrock and stratigraphy to depths of up to 30 metres. While quite extensive experimental work has been carried out using the technique, the method still lies in the realm of a research tool as opposed to an operational tool. In this paper the translation of the impulse radar from being an R & D technique to one which can be used on a routine basis in a practical manner is addressed.

The basic outline of the paper is as follows. (Refer to Slide #1)

First, a review of the basic concept of impulse radar and the basic physical properties which determine the applicability of the method.

Second, we will briefly describe modifications to the system which is backpack portable and easily transportable even through rugged and bush terrain.

Third, we will present some examples of data collected in the field and indicate the flexibility of the system in operation.

Fourth, we will outline the method by which the data is then collated, compiled, digitally processed and reduced to give truly interpreted sections which have been compensated for topographic elevation and velocity variations.

Fifth, we will present the conclusion drawn from the work to date.

2. Basic Principles

Impulse radar is conceptually a very simple technique. It is the electromagnetic analogue of marine echo sounding or seismic reflection techniques. With the radar system, an electromagnetic pulse is generated and transmitted into the ground. Immediately following the transmission of the pulse, the receiver monitors return energy versus delay time. Subsurface features, which are within the range of detectability of the receiver appear as pulses at some delay time after the pulse is generated. By moving the antenna system over the ground one can map the delay time to subsurface reflectors versus position along a profile. The basic concept is illustrated in Slide 2.

The response of the ground to the radar system is governed by two factors, namely, the variation of the EM wave velocity and attenuation characteristics versus depth in the ground. Unfortunately, the radar technique is not universally applicable. Wide variations in soil type present wide variations in attenuation characteristics. Normally, coarse grain sands and gravels are ideal media for the radar technique, whereas fine grain soils, such as silts and clays are much less amenable to the radar methods. Slide 3 summarizes a typical attenuation characteristic observed in geologic materials.

The propagation velocity of electromagnetic waves in soils varies between the speed of light and 1/10 of the speed of light which is .3 metres per ns. The propagation velocity is almost totally determined by the water content of the soil. The higher the water content, the lower the electromagnetic wave velocity. In dry soils, propagation velocities are typically around .1 metres per ns. In wet soils, velocities are normally in the range of .05 to .07 metres per ns. Slide 4 summarizes the velocity observed in some representative materials.

3. Equipment and Field Procedure

The system which we are currently using is a hybrid system. The block diagram of the system is shown in Slide 5. We have made major revisions to the original system design which was manufactured by GSSI in order to come up with a backpack portable system. The antenna system including skis and other support peripherals weighs about 20 pounds. The control unit, tape recorder and associated battery power supplies weigh about 40 pounds. The whole rig, when assembled and backpacked, is illustrated in Slide 6. We are currently going through the steps of redesigning the whole package to make it more compact and even more readily transportable than the system shown here.

Field procedure consists of two major components. First of all, one must address the type of antenna configuration to be used and the logistics of transporting the antenna(s). Second, the optimum time window and settings for the radar system must be addressed. In normal operation, we use a bistatic or two-antenna system; this permits maximum utilization of the system dynamic range. The antenna separation is a variable in the system. Generally, we run it with an antenna separation of about two metres. Wider separations can be utilized when very deep targets are being mapped. Narrower separations can be used if very shallow features are being mapped.

In profiling mode the objective is to transport the antennas at a uniform speed over the ground. This is facilitated by having well defined lines with clear markers spaced along them at well defined intervals. The traverse speed is dictated by the rate at which the crew can transport the equipment.

The most crucial part of a radar survey is setting up the system to obtain optimum data. This necessitates having some prior knowledge of the targets being sought and at what depth they are located. The controls on the radar unit vary the maximum delay time to which signals can be recorded and adjust gains in order to optimally detect the signals reflected from the subsurface. An audio facsimile of the RF signal is recorded on mag tape for later playback. Adjusting the radar unit to get the best results requires a reasonable degree of experience with the equipment and some trial and error experimental work on the site before commencing production work. A series of short profiles and some wide angle reflection and refraction or common depth point soundings are often useful at a site for sorting out this aspect of the set-up.

4. Field Operation and Example Results

The following is a brief case history of a radar survey carried out near Chalk River, Ontario. The regional location map and the detailed survey area are shown in slides 7 and 8. After the system parameters were established, the whole survey grid was surveyed with this set of parameters. The data was played back and all sections were examined to see whether or not total depth of bedrock coverage was obtained. In areas where the bedrock had been deeper than anticipated, those lines were resurveyed at a longer range setting in order to obtain complete bedrock coverage. In production mode, traverse rates in excess of 10 kilometres a day were easy to achieve. In open terrain, this pace could easily be doubled. A snow mobile mounted system on frozen lakes and rivers can achieve over 100 km./day.

Slide 9 shows a very clean record obtained along the road around Twin Lake. The overburden consists of aeolian sands near surface and fluvial sands at depth. Overburden thickness varies from 5 to 20 m. on this section. The water table in this area was relatively near surface (1 - 3 m. deep) This record demonstrates the remarkable resolution which can be obtained with the radar method. The periodic events in midsection are inferred to be ancient sand dunes which have been buried by some subsequent wind action.

A second example of radar sounding is shown in Slide 10. This record was obtained from the ice covered surface of a lake just south of the Twin Lake. At its deepest point, this lake was some 15 m. deep. This record illustrates that the water bottom could be mapped with remarkable detail with the radar system. In the shallow water areas considerable sub-bottom stratigraphy can also be detected. This particular set of data was obtained during relatively poor weather conditions. Considerable rain and melting had caused large pools of water to form on the ice surface. These pools of water are very strong scatterers of electromagnetic energy and tend to generate a lot of near surface hash and garbage on the records. Post field band pass analog filtering has been used to suppress most of the scattered energy. The ice water boundaries are very strong reflectors of electromagnetic energy. The ice water/ice layers near the surface generate a reverberating system which absorbs or back reflects a good deal of the high frequency content of the radar pulse. As a result, bottom reflections tend to be only the low frequency component of the transmitted signal. A similar survey carried out without surface water problems would produce even better results than this set of data.

5. Data Reduction and Interpretation

After the field data has been collected, a graphic picture of the subsurface is immediately available. This picture is one which shows horizontal postion and delay time to buried reflectors. The desired picture is normally the depth to these buried reflectors. As a result, it is necessary to convert the time axis to a depth scale. In addition, the horizontal data scale is not always constant because the data is taken at a variable traverse speed.

The conversion of time to depth is obviously a subjective one and requires knowledge of the geology in the area as well as knowledge of the EM wave velocity versus depth function. In most instances, some handle on these factors can be obtained from drilling in the area and from wide-angle reflection and refraction soundings/CDP soundings with the radar system. Whatever data is used for subsurface control, it is always necessary to simplify the real world to a great extent. With care, however, quite useable depth estimates can be obtained with fairly simple assumptions. Our data processing procedure is all automated onto a computer system. The first step is to digitize all the main reflecting horizons that appear on the raw records section. The next step is to locate the event markers on a plan map in order to get the true spatial coordinates along each traverse line.

The topographic elevation as well as the true position along the line is then digitized and stored in the computer data base with the reflection data. Finally, a best estimate of the velocity depth function versus position is compiled and the whole data set is massaged to generate an elevation corrected section showing the depth to all the reflecting events versus position. The flow chart for this procedure is shown in figure 11. Figure 12 shows the field data from L30S at the Twin Lake site. Figure 13 shows the digitized reflection events without any corrections. Figure 14 shows the section having been corrected for topographic variations and assuming a simplistic velocity function model for the area. A highly interactive software package, which carries out all this work, has been developed recently. A section such as that illustrated here can be digitized and all the information loaded into the machine and the processed data plotted out in the span of about 15 minutes. Most of this time is spent in the mechanical tasks of organizing records and maps.

In areas where there is some subsurface control, initial processed data yields depths which are accurate to about 1 m. When drilling data is utilized to adjust the velocity model, even better accuracy is achieved.

6. Summary and Conclusions

The objective of this paper has been to illustrate the radar method and indicate that it is becoming a more viable and practical tool for routine survey operations. Since it is impossible, in many circumstances, to predict whether or not radar will be a viable technique for solving a particular problem, the ability to get in quickly, do a field test and get out again is very important in the initial stages of developing a new technique. The main results which we want to stress from this talk are the following:

1. A lightweight backpack portable, easily transportable system has been assembled.
2. This system can be utilized in rugged and bush terrain provided that lines have been cut through the woods.
3. A facility exists for rapid and interactive interpretation of radar sections.
4. Simplifying the system has reduced the costs of operational surveys by more than a factor of 2.

We hope that the results of this talk will have been of interest to you and will make you think of utilizing the radar method in the future. If you should have questions, please contact personnel at A-Cubed for further information on radar surveys and methods.

LIST OF SLIDES

AN APPLICATION OF IMPULSE RADAR TO DETAILED MAPPING OF BURIED BEDROCK TOPOGRAPHY

BASIC CONCEPTS

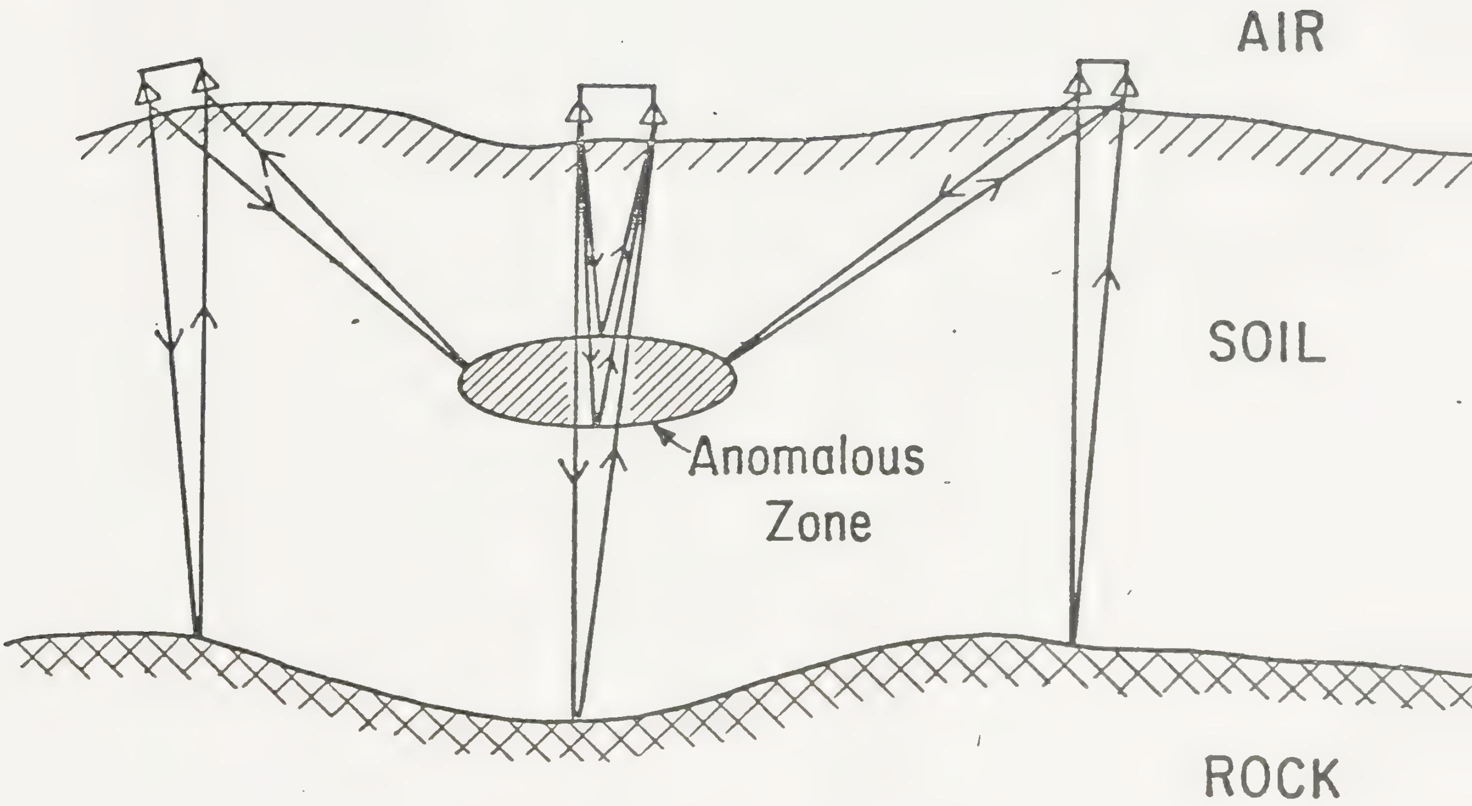
EQUIPMENT AND FIELD PROCEDURE

PRESENTATION OF RAW RADAR DATA

DATA REDUCTION AND INTERPRETATION PROCEDURES

SITE SPECIFIC EXAMPLE

SUMMARY AND CONCLUSIONS



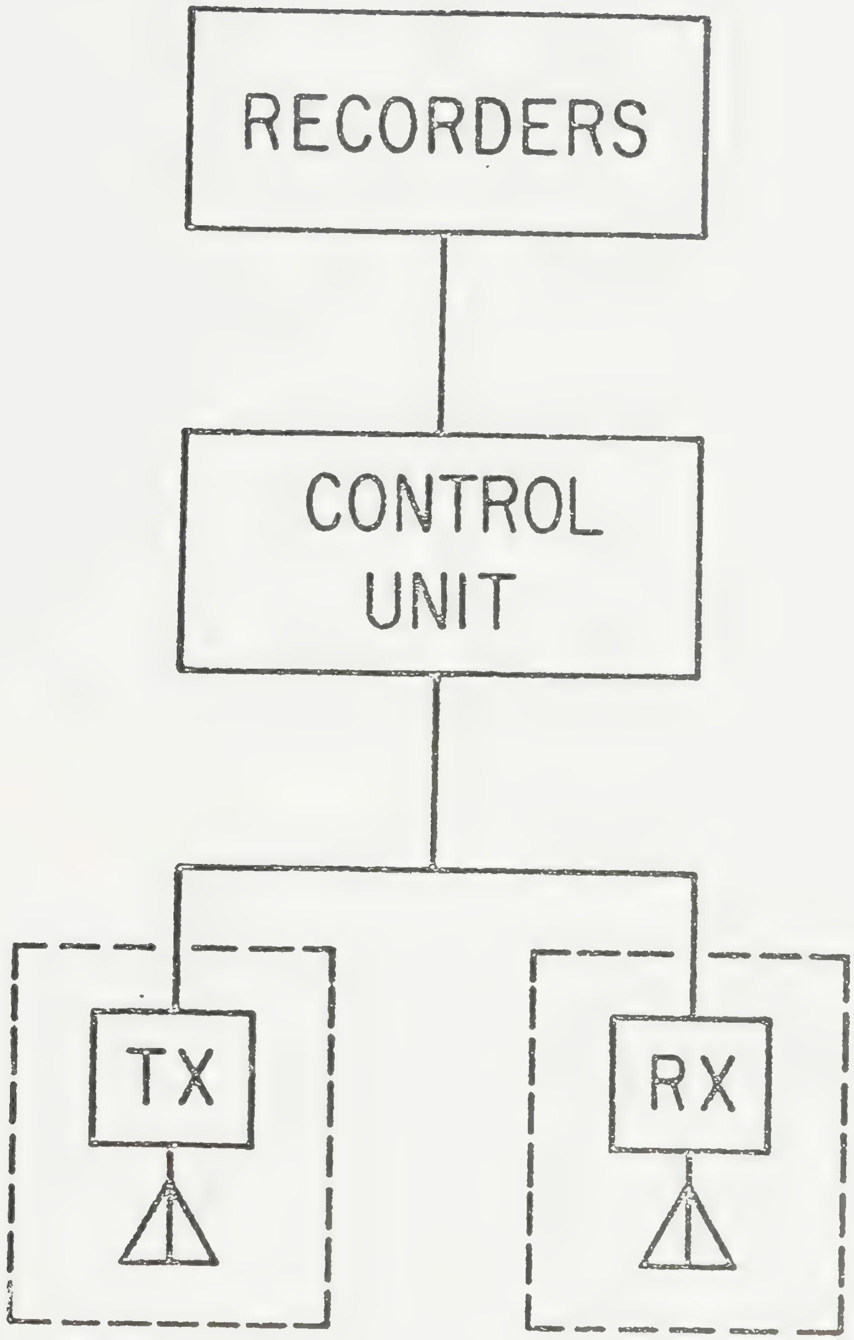
SLIDE #2

ATTENUATION SUMMARY

DRY SANDS/GRAVEL	.01 – .1	dB/m
WET SANDS/GRAVEL	.03 – .5	dB/m
CLAYS/SILTS	.1 – 10	dB/m
FRESH WATER	.01 – .1	dB/m
SALINE WATER	.1 – 100	dB/m

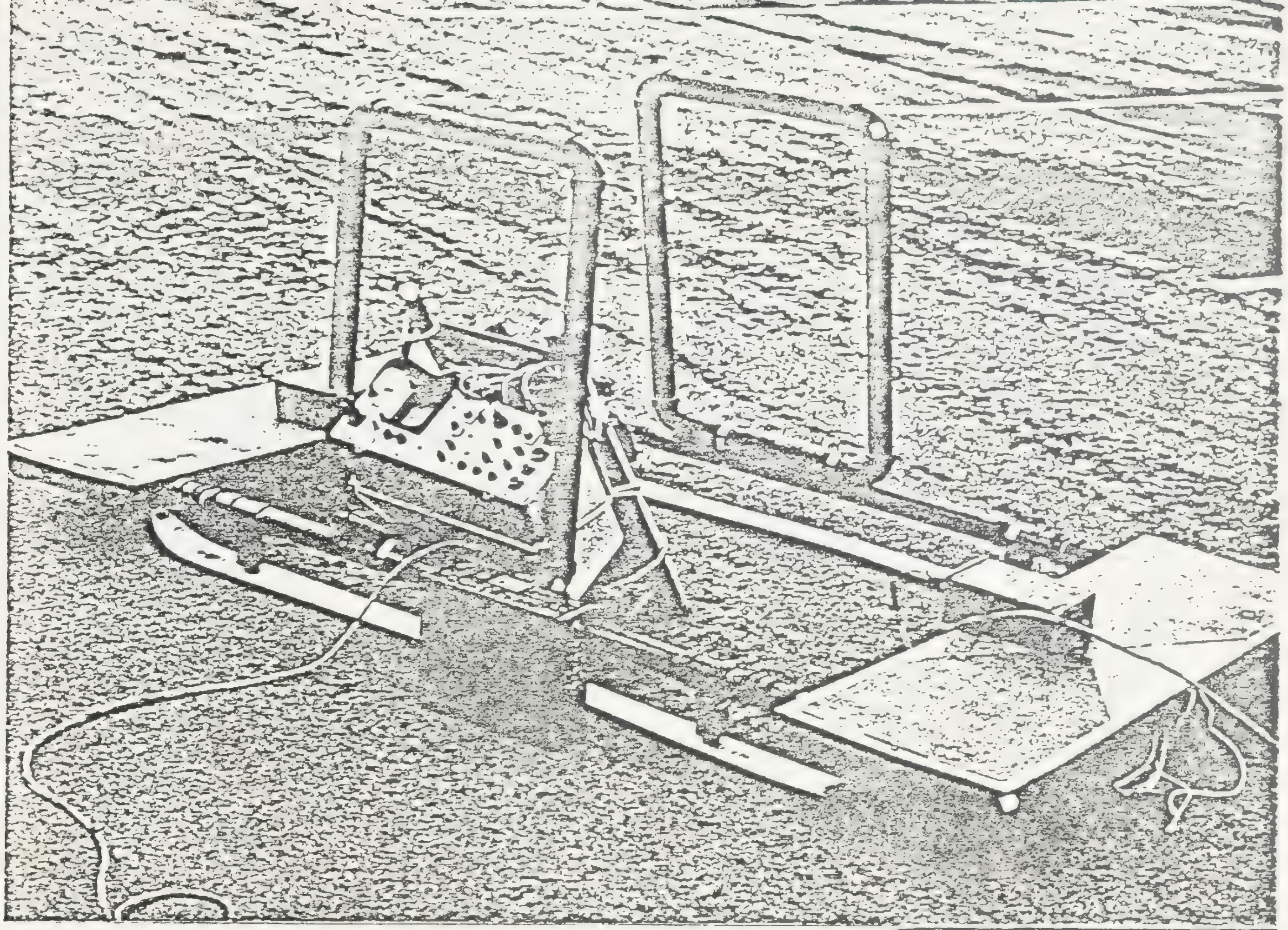
VELOCITY SUMMARY

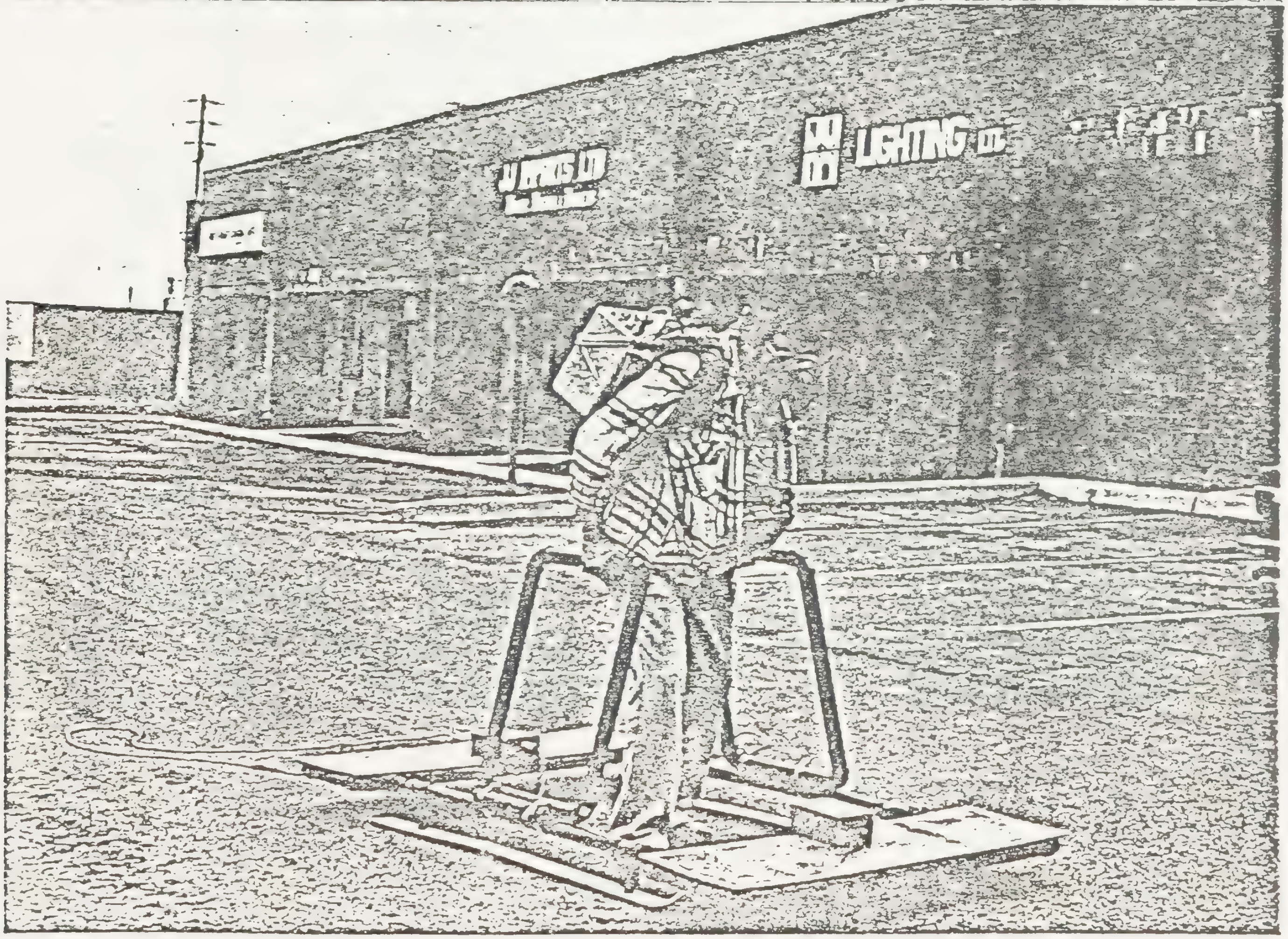
DRY SANDS/GRAVEL	100 - 150	m/uS
WET SANDS/GRAVEL	60 - 80	m/uS
DRY CLAYS/SILTS	90 - 120	m/uS
WET CLAYS/SILTS	50 - 70	m/uS
WATER	33	m/uS
AIR	300	m/uS



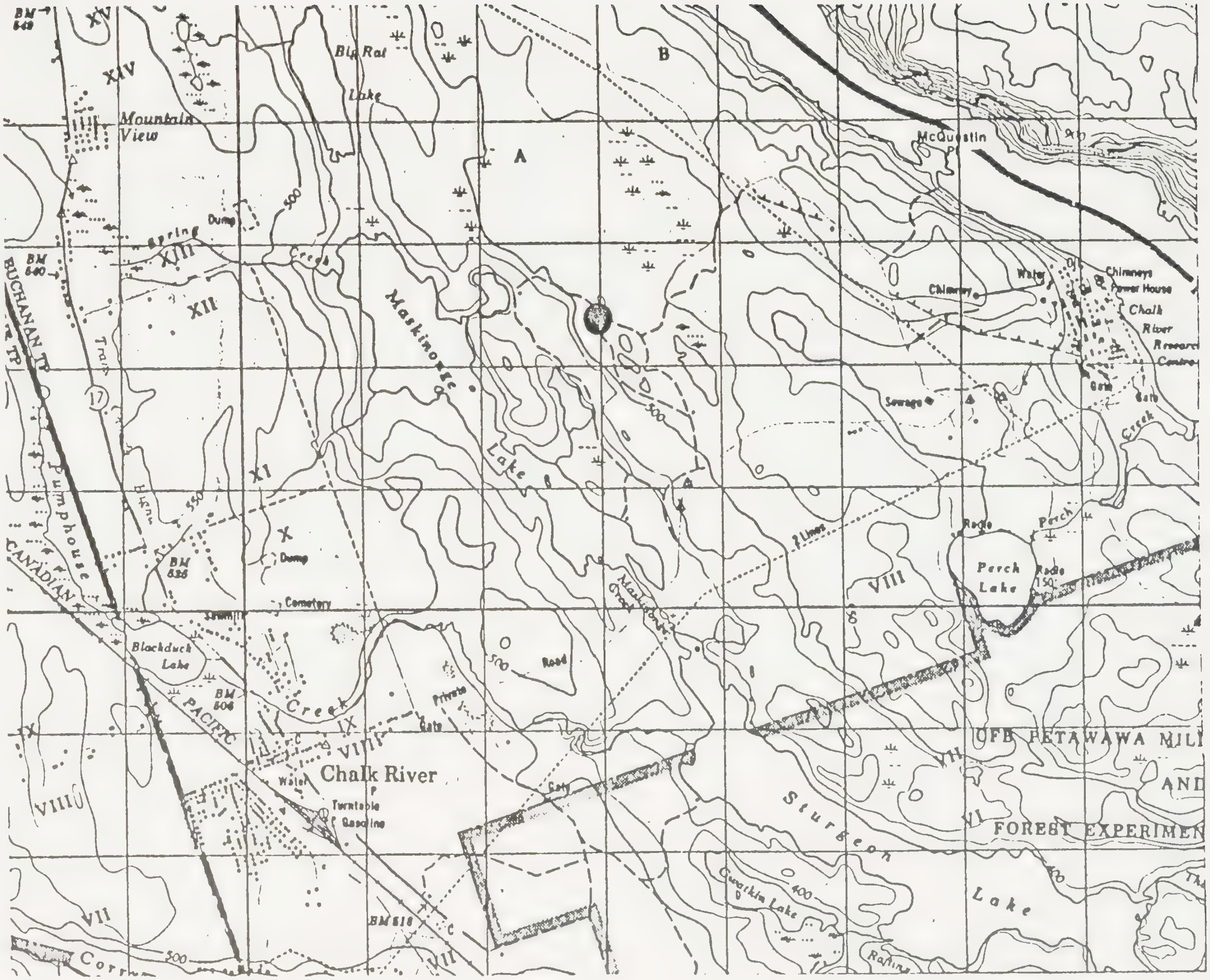
RADAR SYSTEM
BLOCK DIAGRAM

. SLIDE #5

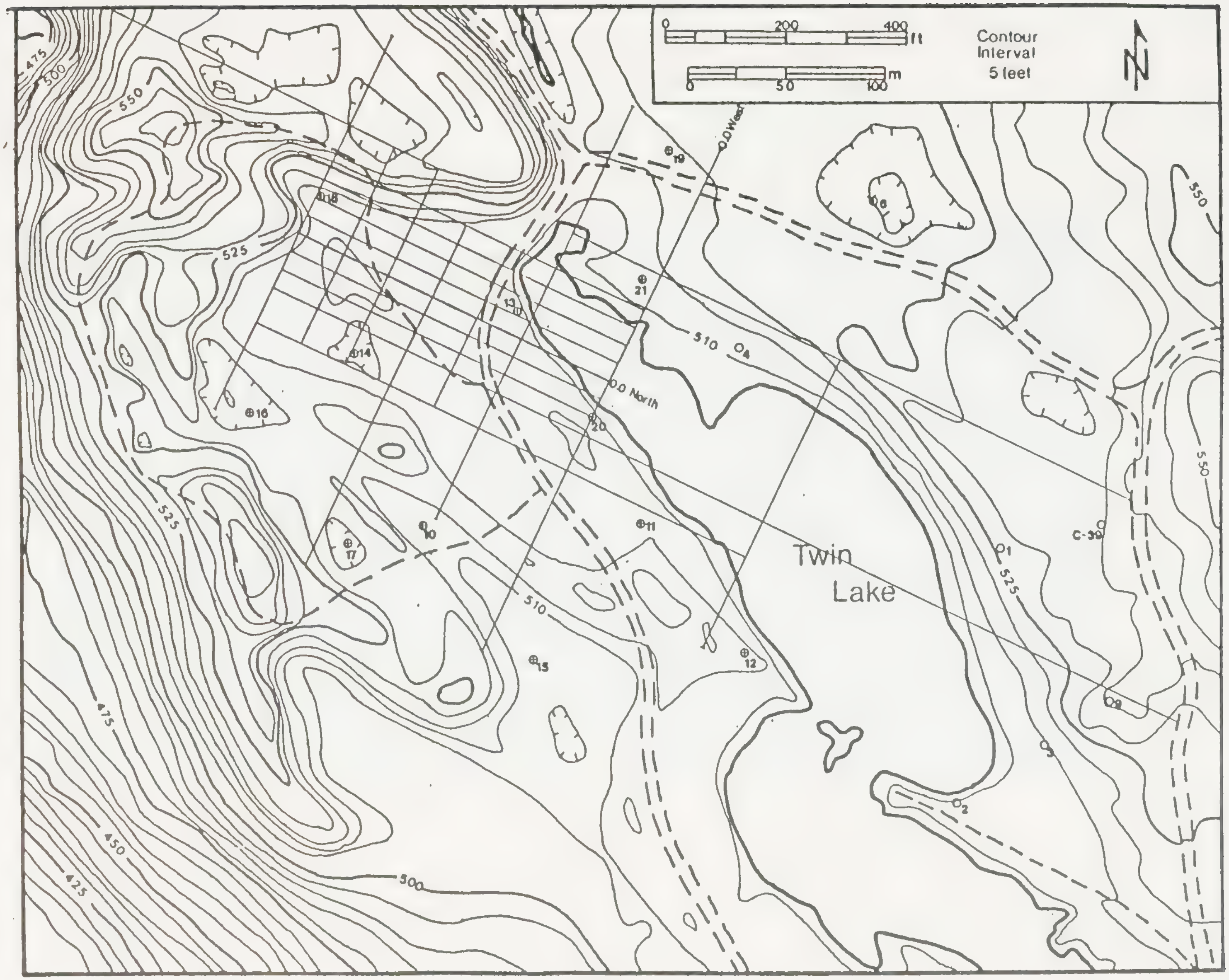




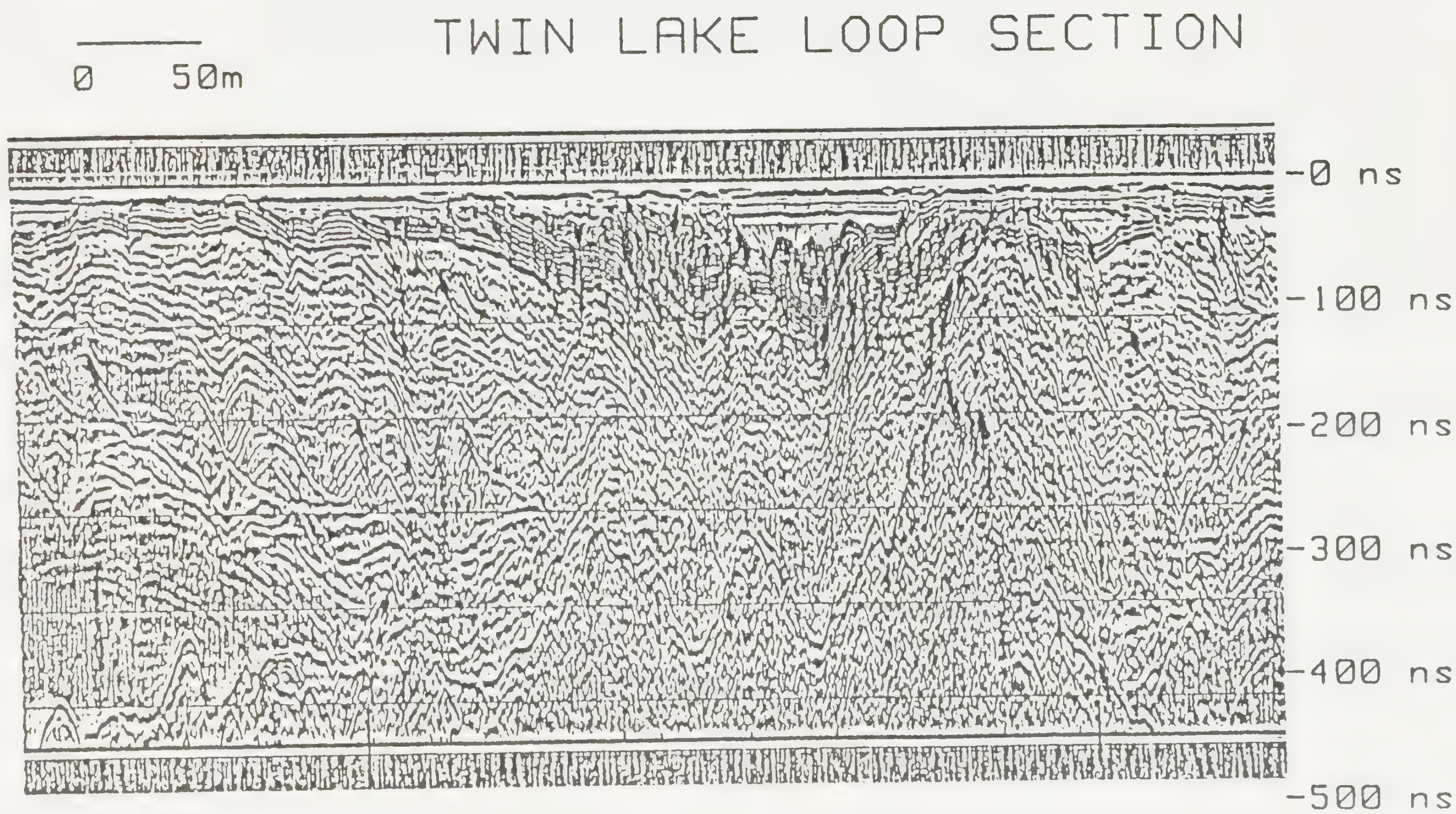
SLIDE #6


Big Rat Lake
Mountain View
McQuestin Pt
Maskinonge Lake
Chalk River Research Centre
Chimneys
Power House
Perch Lake
Sturgeon Lake
Chalk River
Blackduck Lake
Pumphouse
CANADIAN PACIFIC
BUCHANAN TP
FOREST EXPERIMEN
Dump
Cemetery
Sewage
Turntable
Gasoline
Creek

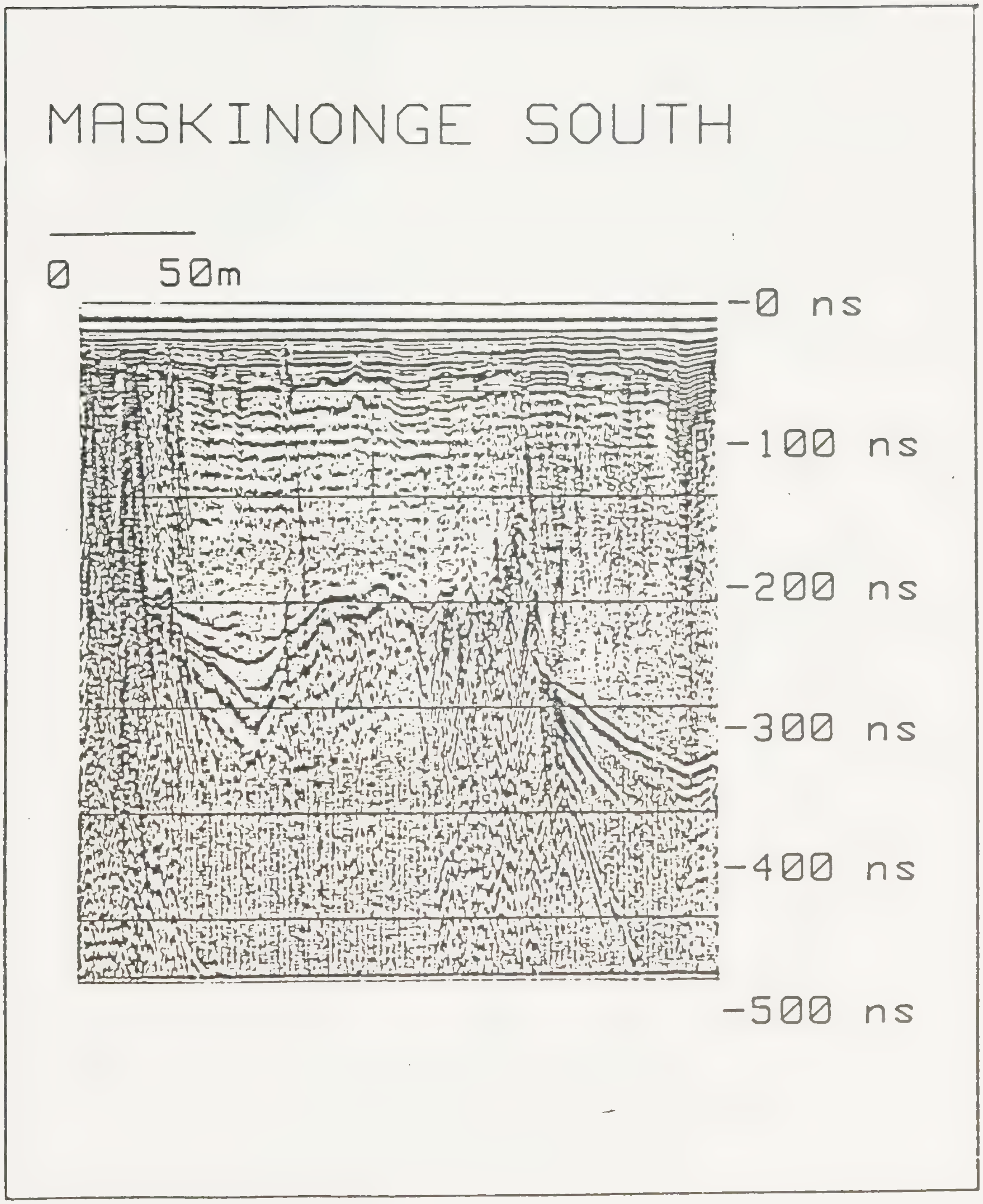
SLIDE #7


0 200 400 ft
0 50 100 m
Contour Interval 5 feet
N
0.0 West
0.0 North
Twin Lake
550
525
510
500
475
450
425
C-39
19
21
18
14
16
13
11
20
10
17
11
15
12
1
2
3
4
6
9

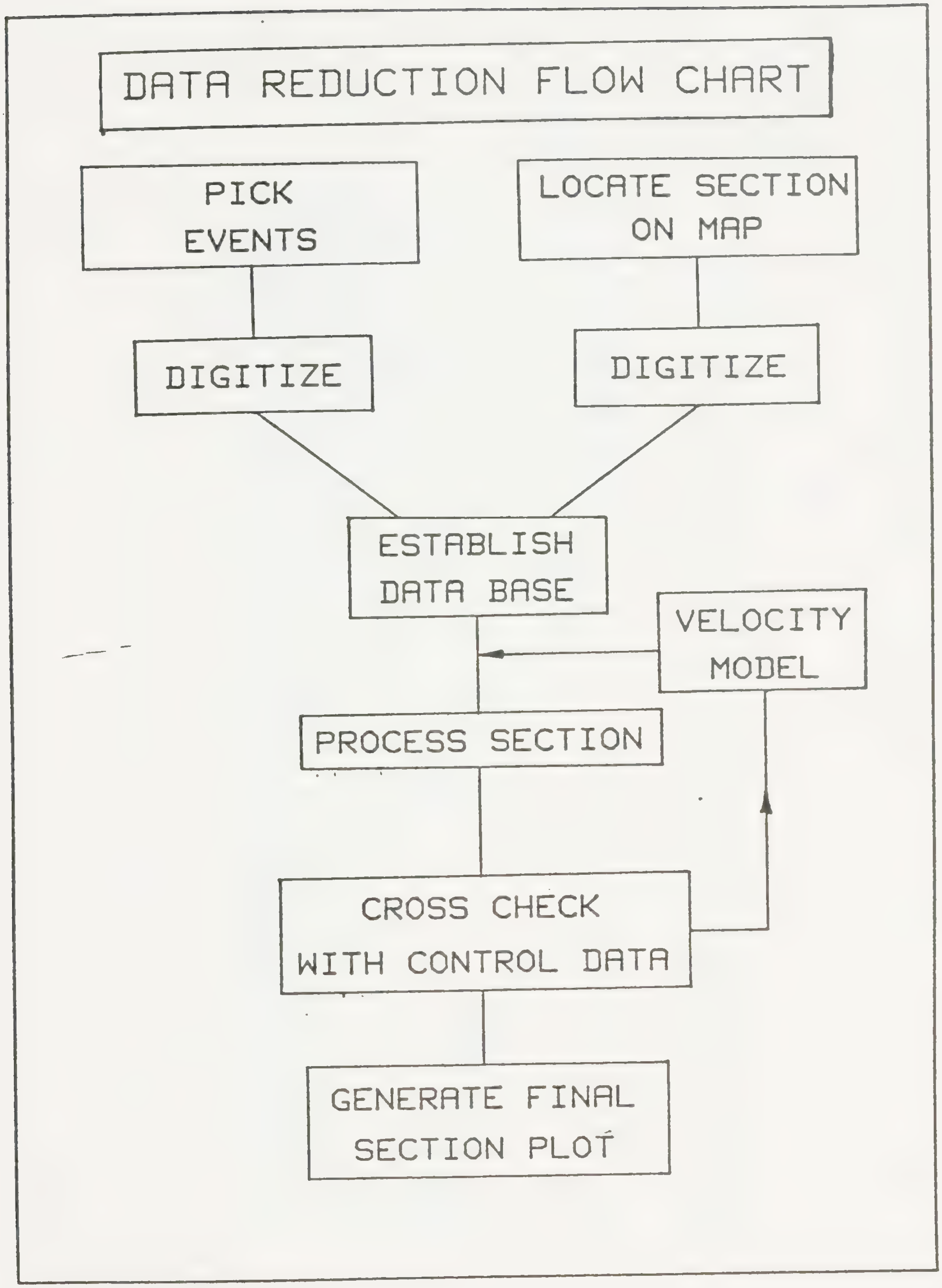
SLIDE #8


TWIN LAKE LOOP SECTION
0 50m
-0 ns
-100 ns
-200 ns
-300 ns
-400 ns
-500 ns

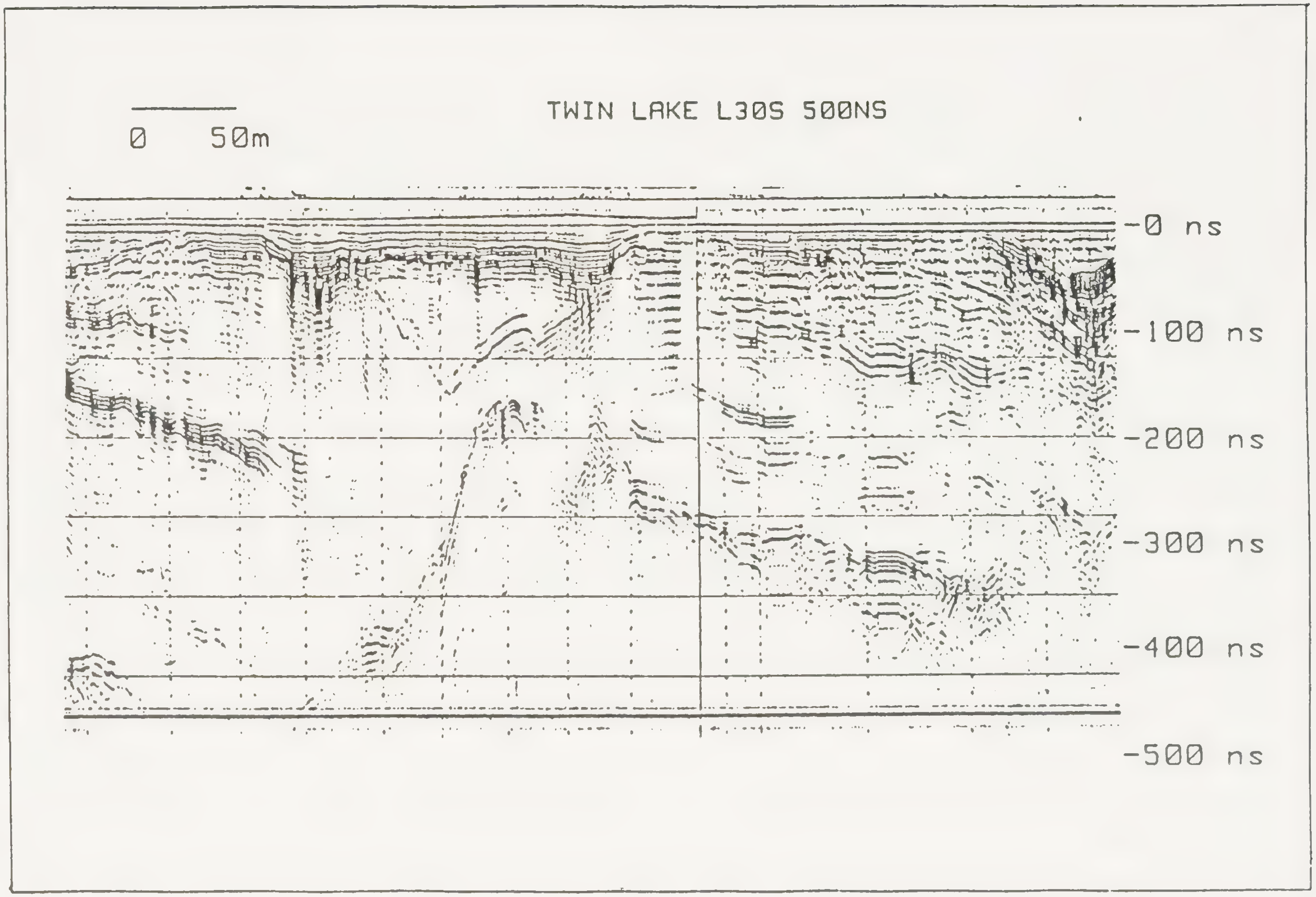
SLIDE #9



SLIDE #10

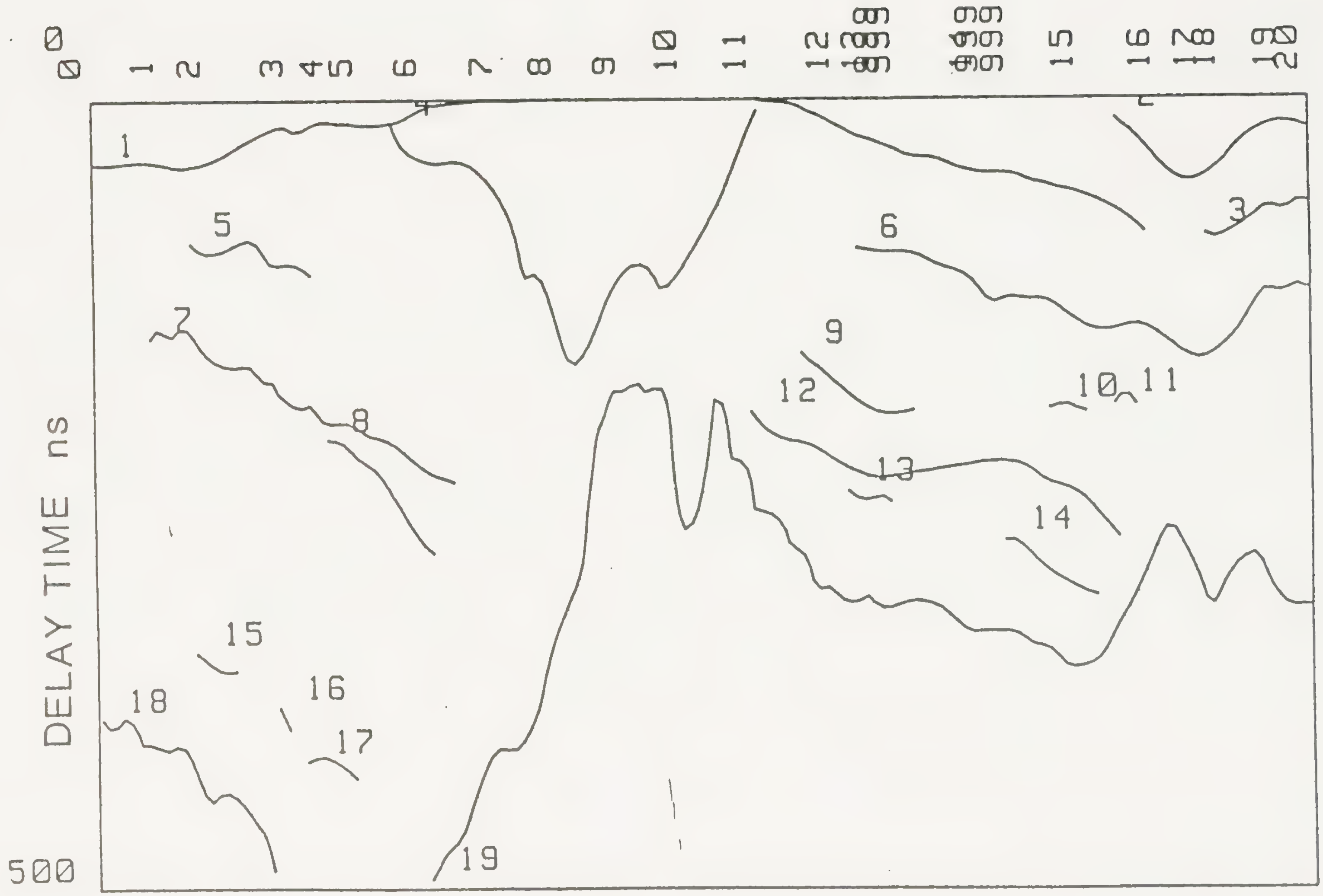

DATA REDUCTION FLOW CHART
PICK EVENTS
LOCATE SECTION ON MAP
DIGITIZE
DIGITIZE
ESTABLISH DATA BASE
VELOCITY MODEL
PROCESS SECTION
CROSS CHECK WITH CONTROL DATA
GENERATE FINAL SECTION PLOT

SLIDE #11



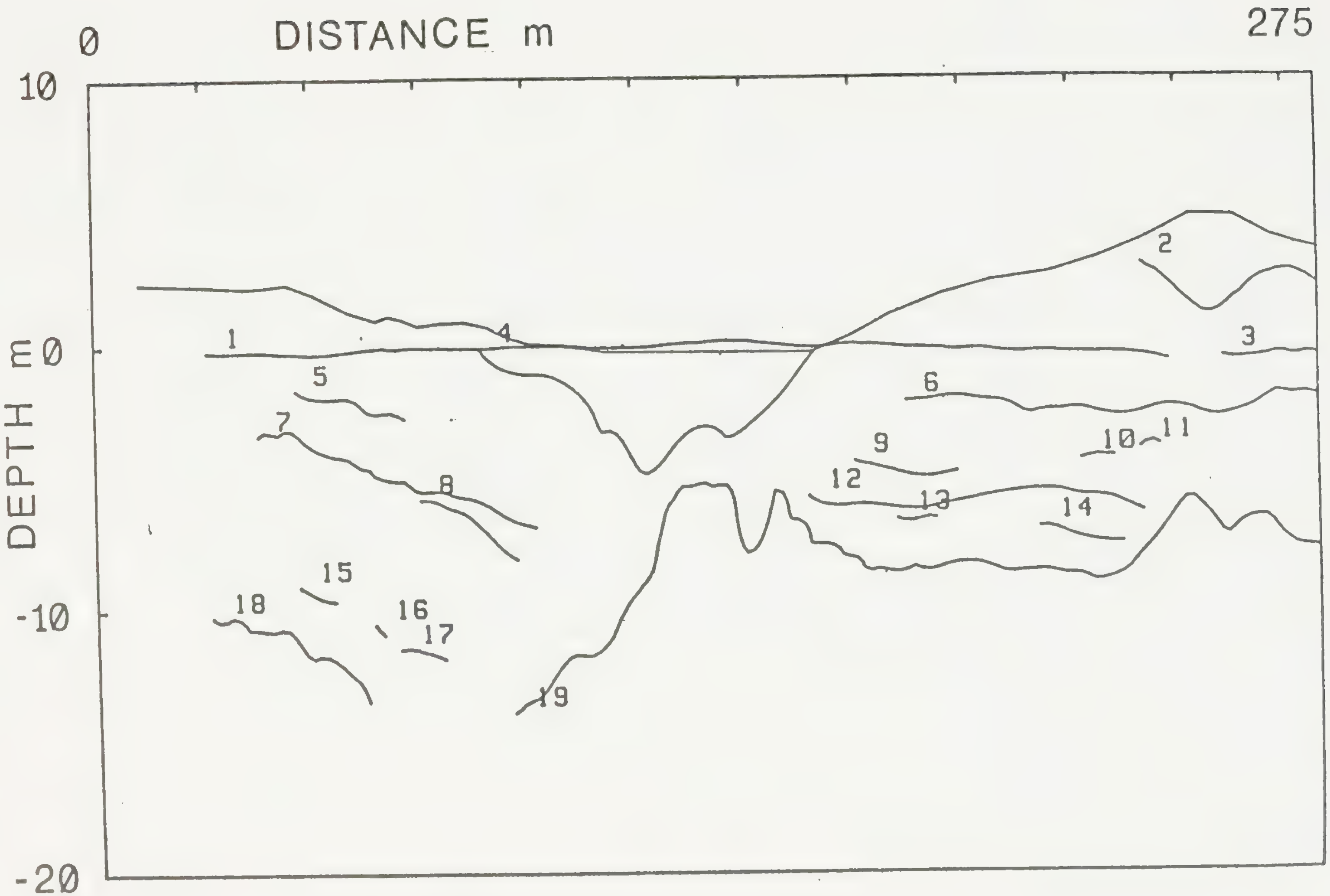
SLIDE #12

FILE # 018 TWIN LAKE L30S 500NS



SLIDE #13

FILE # 018 TWIN LAKE L30S 500NS



SLIDE #14

SUMMARY

RADAR MAPPED BEDROCK TO DEPTHS
OF 30M

DEPTH RESOLUTION OF 1M

RAPID RECONNAISSANCE RATES
(>10 KM/DAY)

COMPUTERIZED INTERPRETATION AIDS
RAPID REPORTING